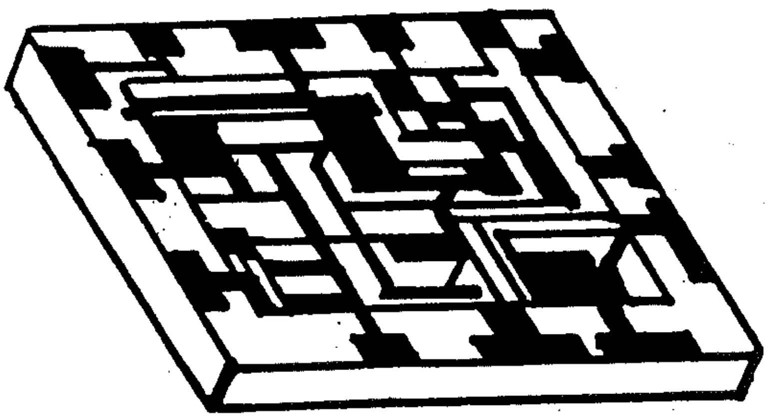
NATIONAL SECURITY ASSESSMENT OF THE U.S. SEMICONDUCTOR WAFER PROCESSING EQUIPMENT INDUSTRY



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National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry

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EXECUTIVE SUMMARY

National Security Assessment of the Semiconductor Wafer Processing Equipment Industry

This assessment was initiated by BXA's Office of Industrial Resource Administration (OIRA) in response to the 1989 Department of Defense Critical Technologies Plan submitted to the U.S. Congress. Semiconductor wafer processing equipment was identified as a key supporting technology for 13 of the 20 technologies appearing on DOD's list. In addition, there was concern over the loss in the U.S. manufacturing base for this equipment in recent years, as well as the large number of foreign acquisitions in this sector.

Semiconductors are used in a multitude of products, both consumer and defense-related, and play an important role in the nation's military and economic security. They are found in everything from personal computers to precision guided missiles, and are crucial not only for enhancing industrial capabilities but also as a source of technical military advantage.

The wafer processing equipment industry is vital to the success of semiconductor manufacturing. Advances in semiconductor devices cannot occur without supporting improvements in the technology used to produce them. Therefore, the health of the nation's wafer processing equipment firms affects the viability of the semiconductor industry and, indirectly, all of the industries where semiconductors are used.

The U.S. wafer processing equipment industry experienced a drastic loss of market share during the 1980s. Worldwide sales of all semiconductor manufacturing equipment quadrupled between 1980 and 1988. During that time, the U.S. share of these sales dropped from 75 percent to 49 percent, while Japan's share rose from 18 percent to 39 percent. A major factor leading to this decline was the loss of key semiconductor and electronics markets to Japanese producers.

Semiconductor wafer processing equipment accounted for about one-half of the total U.S. semiconductor manufacturing equipment sales of $5 billion in 1989. Wafer processing equipment includes the machinery used in the "front-end" processes of semiconductor manufacture: microlithography, deposition, etch and strip, ion implantation, and thermal processes. The remaining equipment segments are test and assembly.

More than 200 companies compete in the world market for wafer fabrication equipment. Almost all of the firms are based in the United States, Japan and Europe. Over 100 U.S. firms serve the market, and most are small, niche producers, with sales of $5-$25 million. However, because of the high costs of doing business in this industry, world market share is increasingly concentrated among a few large companies.

In 1980, U.S. consumption of semiconductor manufacturing equipment was nearly double that of Japan; by 1988, Japan's consumption had edged past that of the United States. In 1982, the United States consumed 58 percent of the world's production of SME, while Japan accounted for just over 29 percent. In 1988, Japanese and U.S. consumption were roughly equal, at about 39% of world consumption each.

Wafer processing equipment can be broken down into five categories, based on different steps in the production process. The five major categories are:

Microlithography can be considered the most important machinery in the semiconductor manufacturing process; improvements in this equipment are key to improvements in the integrated circuits themselves. Japan's share of the rapidly expanding wafer stepper market grew from 39 percent in 1984 to 74 percent in 1989, while the U.S. share fell from 60 percent to 15 percent in the same period.

Deposition, along with microlithography, is a key technology driving the semiconductor industry, and it was the fastest growing sector of the equipment industry during the 1980s. Chemical vapor deposition (CVD) was the largest and fastest growing segment in 1989, accounting for $621 million of the $1.1 billion deposition market. U.S. firms made up 60 percent of the world market for CVD, while Japan captured about 22 percent. In 1989, Japanese firms accounted for 55 percent of the $350 million world market for physical vapor deposition equipment, and U.S. manufacturers followed with 27 percent. U.S. firms dominated the $166 million epitaxy market in 1989, with a 50 percent share, followed by European producers with about 28 percent.

Dry etching accounted for over 80 percent of the $874 million **etching** market in 1989. U.S. firms led the way, with 60 percent market share, down from 70 percent in 1984. Japanese producers followed with 32 percent, up from 25 percent in 1984. In the much smaller and flat market for wet etching equipment, U.S. firms controlled 75 percent, down only slightly from 1984, and Japanese firms controlled the remainder.

The **ion implantation** equipment market was $564 million in 1989, up from $395 million in 1988. U.S. firms continue to dominate this market, with about 75 percent of sales, and Japanese companies make up most of the remaining 25 percent.

The equipment used in **thermal processes** accounts for less than 10 percent of the world market for wafer fabrication equipment. World sales of thermal processing equipment totalled $343 million in 1989, and almost 90 percent of this was diffusion furnaces. Japanese firms claimed 60 percent of the worldwide market in 1989, up from 39 percent in 1984, while U.S. firms' share declined from 48 percent to 35 percent in the same period.

OIRA survey data shows a slump in shipments of wafer processing equipment during the mid-1980s. Dollar shipments for the group surveyed reached a low point in 1986, then rose, irregularly, to a level in 1989 that was higher than before the decline. Respondents' unit shipments reached their lowest level in 1987; while recovering somewhat, units shipped have not returned to their pre-downturn level.

Capacity utilization for the surveyed firms varied by category of wafer processing equipment produced. On average, the respondents reported operating at only 42 percent of capacity during 1989. Between categories of equipment, however, there was significant variation. Not surprisingly, those categories where the United States lost the most market share during 1984-89 were the categories where the lowest capacity utilization was reported.

The surveyed firms exported at a much higher level than most other U.S. manufacturing sectors. Respondents exported about 50 percent of their products. The largest markets for U.S.-produced equipment are Japan and Western Europe. Not unexpectedly, the segments of the wafer processing equipment industry showing the greatest decline in market share are those who export the least.

Employment figures for 1985-89 closely track shipment data. Employment levels reached a low point in 1987 and have since recovered. A relatively high percentage of employees, about 20 percent, were categorized by survey respondents as "scientists and engineers", reflecting the complexity of the equipment and the rapid pace of change in its technology. Production workers made up 45 percent of the workforce overall, and management and administrative employees accounted for the remaining 35 percent.

Respondents maintained their spending on research and development, even when sales declined. R&D expenditures remained relatively constant from 1985 to 1988, ranging from $50 to $60 million per year, or 15 to 20 percent of net sales, far exceeding the average for U.S. industry. Most of this was funded in-house, although toward the end of the period there are indications of increased funding from other sources, such as the government, joint ventures, and customers.

Survey data indicate a decline in capital investment in plant and new machinery. The decline was seen not only in dollars spent, but also in terms of investment as a percentage of net sales, which peaked at 10.7 percent in 1987 and declined thereafter, reaching 2.1 percent in 1989.

Firm profitability closely tracked the industry's shipment trends. Overall, the firms surveyed reported losses during 1986 and 1987, as would be expected, given shipments data. Individual responses varied widely; while some firms remained profitable throughout the period, others experienced losses, and some experienced wide variations in performance.

Firms were asked how long it would take to double their monthly unit production rate in case of a national emergency. Given the assumption of full government financial assistance, firms reported that such a doubling of output would require nearly a year. The biggest constraint to such an expansion would be the shortage of skilled labor, followed by lead times for needed parts, materials and equipment, often obtained from foreign sources.

All but two of the nine firms surveyed mentioned substantial reliance on foreign suppliers for necessary parts and equipment needed to produce wafer processing equipment. Respondents' imports of major parts and components equalled nearly 7 percent of their reported costs of goods sold, or $30 million. This figure is probably an understatement: certain items are obtained from domestic distributors representing foreign sources. Optics for lithography was one such product; vacuum and turbo pumps and electronics were other areas where foreign sources were relied upon, mainly due to the lack of an adequate domestic supplier.

The surveyed firms stated that, while they maintained the lead in a number of product areas, they were losing this lead to foreign competitors. Several firms cited overall technology and innovation as areas where they retained a competitive edge, but few mentioned product quality and government assistance as sources of advantage, and none mentioned capital costs or the business environment.

Several factors influence the competitiveness of the United States wafer processing equipment industry. First and foremost is the health of the semiconductor industry. The U.S. merchant semiconductor industry has suffered in recent years due to the migration of its customer base offshore, particularly to Japan. This trend has decreased the domestic market for U.S. wafer processing equipment manufacturers, and, aside from a few ventures, the Japanese market is largely served by Japanese equipment manufacturers.

Industry structure also plays an important role in the competitiveness of the U.S. industry. First, firms in the U.S. industry are relatively small compared with major Japanese firms, putting them at a disadvantage in terms of available capital for research and development and the ability to carry inventories. Also, major Japanese and European competitors are highly vertically integrated, further expanding their sales base and often providing a ready-made market for their products. Strong producer/supplier relationships in Japan make it difficult for U.S. firms to penetrate the market.

The level of government support is another key competitive factor. The Japanese, European and U.S. governments have all sponsored research programs for their wafer processing equipment industries. There were significant differences in the aims and nature of these programs. U.S. programs have typically pursued defense-related goals while foreign programs have addressed commercial objectives. Also, Japanese and European government projects emphasized joint research and cooperation among firms, while cooperation was not emphasized in most U.S. projects.

SEMATECH, the most recent and highly publicized U.S. government effort, is a semiconductor research and development consortium founded in 1987 to boost the manufacturing technology of the U.S. semiconductor industry. Its focus has been on equipment design as well as production techniques, and is less closely linked to military applications than previous efforts. Also, it appears to be fostering cooperation among firms.

Unfair trade practices in both the wafer processing equipment and semiconductor industries have hurt U.S. equipment manufacturers. There have been reports of foreign competitors selling equipment at prices below cost, and incidents of dumping of semiconductor devices are well-documented.

The high level of foreign investment is additional evidence of the decline of U.S. control over semiconductor production and technologies. In recent years, there have been numerous foreign acquisitions of U.S. firms in the equipment, device and materials industries. The small size of most U.S. wafer processing equipment producers, as well as their "niche" technologies, have made them attractive targets. In addition, a devalued dollar contributes to the ability of foreign firms to buy U.S. companies at "cheap" prices.

Developing the wafer processing equipment needed to keep up with advances in semiconductors themselves is technologically demanding and expensive. As a result, equipment firms spent about 17 percent of sales on research and development in recent years, as opposed to 5.9 percent of sales in 1979. One area receiving a lot of attention is microlithography, and, in particular, x-ray lithography. Some experts believe that this technology will be critical to improvements in semiconductor performance for future defense and commercial applications. However, based on high levels of Japanese public and private R&D, U.S. R&D expenditures may not be sufficient to develop and commercialize this technology first.

Overall, the U.S. wafer processing equipment industry suffered a drastic loss in market share during the 1980s. This industry is critical to the economic well-being and defense security of the nation. We recommend the following actions be taken by industry and/or government to improve the domestic industry's competitive position:

- Wafer processing equipment producers are encouraged to develop mutually-beneficial strategic alliances with foreign partners to gain access to foreign markets and research and development funds.

- Our assessment has uncovered an apparent positive trend toward closer relationships between U.S. semiconductor equipment producers and chip manufacturers. U.S. industry is encouraged to expand and further develop these interrelationships, in both domestic and increasingly internationalized operations.

- In addition to its export promotion activities, the U.S. Government should ensure that the ability of U.S. wafer processing equipment producers to sell overseas is not hindered by foreign unfair trade practices, customs laws, regulations, and directives.

- The U.S. Government should improve data collection and reporting for the wafer processing and other semiconductor manufacturing equipment industries.

INTRODUCTION

A. Background

The U.S. Department of Commerce, Bureau of Export Administration (BXA) is delegated authority under the Defense Production Act of 1950, as amended, (DPA) and related Executive Order 12656, to identify critical industries; assess their capabilities to meet national security needs; evaluate current and potential production bottlenecks; and propose remedial action when necessary. The Office of Industrial Resource Administration (OIRA), Strategic Analysis Division, is responsible for conducting these national security industrial assessments.

In the course of an industry assessment, particular consideration is given to such factors as: industry structure, raw material availability, investment, foreign sourcing and dependency, labor and material cost, productivity, technological factors, trade patterns and market trends, and international competitiveness. Necessary data are collected by the Strategic Analysis Division from the private sector under authority of Title VII of the DPA. Independently, as well as in cooperation with the Armed Services, OIRA has completed a number of national security assessments including studies of the precision optics, gas turbine engine, anti-friction bearing, machine tool, investment casting, industrial fastener, plastic injection molding machinery, robotics, gear and crude oil/petroleum products industries.

This industrial capability assessment focuses on production of wafer processing equipment -- all types of equipment used in the front end processes of turning raw wafers into semiconductor chips, either individual or integrated circuits. This analysis excludes that equipment used to test, assemble, and package the finished product. The front end segment of semiconductor wafer processing accounted for about half of the total U.S. semiconductor manufacturing equipment industry sales of $5 billion in 1989.

OIRA initiated this assessment of the semiconductor wafer processing equipment industry in January, 1990. Unlike many previous OIRA industrial capabilities studies, this assessment was conducted independently from the DOD Armed Services. However, a major contributing factor to OIRA initiating this assessment was the 1989 Department of Defense Critical

Technologies Plan submitted to the U.S. Congress. In that report, the Department of Defense (DOD) highlighted 20 technologies vital to ensuring the long-term qualitative superiority of U.S. weapon systems. Semiconductor wafer processing equipment, while not listed as one of the twenty, was identified as a key supporting industry sector for 13 out of 20 technologies. In addition, there was concern over the loss in the U.S. manufacturing base for this equipment, and over the increasing number of foreign acquisitions of U.S. firms in this sector.

B. Importance of Industry to National Security

Advances and growth in semiconductor technology have been a driving force behind tremendous improvements in productivity and performance throughout the U.S. economy. Semiconductors are now used pervasively in virtually every aspect of the economy. They are the enabling technology for everything from computers and telecommunications to consumer electronics, computer-assisted engineering and manufacturing, and precision guided munitions.

Because of the broad applications for semiconductors throughout the industrial base, the devices are uniquely important for the nation's military and economic security. The defense posture of the United States is heavily based on technological superiority rather than numerical advantage. Much of this technological edge can be traced first to electronic systems, and ultimately to semiconductors. The importance of semiconductors, and the consequences of losing a technological lead in them, has been recognized by both the Reagan and Bush Administrations, the Congress, and private industry and led to the 1987 establishment of SEMATECH, a government/industry semiconductor research and development consortium based in Austin, Texas.

The wafer processing equipment industry is extremely crucial to the success of semiconductor manufacturing. This equipment is the core technology for improvements in integrated circuit performance and capabilities. For example, modern integrated circuits would not be possible without improvements in microlithography and mask making equipment. The wafer processing equipment industry continues to drive semiconductor capabilities through increased miniaturization and storage capacity. Because of the many uses for and importance of semiconductors, the loss of leadership in wafer processing technologies undermines not only the semiconductor industry, but also profoundly affects the ability of a broad range of industries to compete in the development of innovative technologies well into the future.

C. Survey Methodology and Scope

In February of 1990, a survey questionnaire was distributed to nine firms in the semiconductor wafer processing equipment industry under mandatory collection authority provided under Section 705(e) of the DPA. The firms surveyed included large and small producers of: aligners and lithography systems (e.g., E-beam mask makers); thin and thick film deposition (e.g., chemical vapor deposition); ion implantation; and thermal processes (e.g., diffusion/oxidation furnaces). A copy of the survey instrument is attached at Tab A. To supplement the industry survey, a search of available literature and statistics was conducted and related industry visits were made.

The establishments involved in the production of semiconductor manufacturing equipment are included in a five-digit product class of the Standard Industrial Classification (SIC) system. This product class, SIC 35596, debuted in 1987 and is a subset of the four-digit industry group, SIC 3559 (Special Industry Machinery, Not Elsewhere Classified). This four-digit group includes everything from cotton ginning and cement making machinery to tobacco processing machinery and tire building equipment.

Unfortunately, there is much more information available at a greater frequency at the four-digit level than at the five-digit level. At the four-digit level, industry data on employment, wages, cost of materials, value added, industry shipments, and new investment is published each year. At the five-digit level of detail, information is published once each five years in the Census of Manufactures.

Given the wide range of machinery and equipment included in SIC 3559, drawing conclusions about the semiconductor manufacturing equipment industry from data at the four-digit level would be unrealistic. At the five-digit level, the most recent information available is the 1987 Census of Manufactures. Unfortunately, much of the data on this industry was withheld from the Census publications because the estimates did not meet the Census publications' standards or to protect the confidentiality of data for individual firms. However, the Census of Manufactures was utilized where adequate data were available. The other main source of information utilized, other than the OIRA survey, was VLSI Research.

INDUSTRY OVERVIEW

A. MANUFACTURING PROCESS

The electronics industry has grown remarkably since its birth at the beginning of the century with the creation of the early vacuum tubes, followed by the research that led to the semiconductor diode and transistor in the late 1940s. The integrated circuit followed in 1958, the invention of Jack Kilby, an engineer working at Texas Instruments, and Robert Noyce, working independently, at Fairchild. In 1970, the first microprocessor, an electronic integrated circuit that performs the function of a central processing unit in a computer, was produced. Today, these integrated circuits are found in a multitude of consumer and defense-related products.

The first step in the creation of an integrated circuit, or chip, is the formation of a wafer. Silicon is typically used, although other crystalline substances, such as germanium or gallium arsenide, can also be used. Silicon, an element in common sand, is abundant, less expensive, and possesses faster signal transfer capabilities than germanium; gallium arsenide, while faster in terms of signal transfer capabilities, is more brittle and more expensive than silicon. In addition, gallium arsenide is desirable for defense applications because it is not sensitive to electro-magnetic pulse.

The wafers are sliced from silicon ingots. Ingots are cylinders which are grown by melting and then crystallizing pure silicon. Each slice must be very precise in its thickness: the wafers may be as thin as 0.25mm but are often in the thickness range of 0.5 to 0.8mm. Next, the wafers are ground, lapped and then polished to a mirror-like finish.

The silicon wafer is first exposed to pure oxygen in order to grow a thin layer of silicon dioxide, which does not conduct electricity, and then coated with a photoresist. As the name implies, a photoresist is a chemical that is sensitive to light. In the next step, called microlithography, or masking, a pattern is written onto the photoresist with light, electrons, x-rays or ions. The photoresist either hardens where the light hits it and remains soft in unexposed areas, or vice versa, depending on the type of photoresist used.

Next, in the etching step, a solvent dissolves away the unexposed resist, revealing the silicon dioxide underneath. This part of the silicon dioxide is chemically etched to reduce its thickness. The hardened photoresist is then also dissolved, leaving an area of silicon dioxide. In the second masking, layers of polysilicon, which conducts electricity, and photoresist are applied to the wafer, and, once again, a pattern is exposed onto the photoresist.

In the second etching step, the unexposed, soft photoresist is dissolved, and then the polysilicon and silicon dioxide are etched away, revealing the silicon base in the areas where the unexposed photoresist was. The hardened photoresist is also removed, revealing an area of polysilicon.

In the next step, called doping, the layers are treated with dopants, which are chemical elements such as arsenic or boron, that change the conductivity of the wafer. Two methods are available. The first, and oldest, technique is called diffusion. The wafers are placed in a furnace and exposed to a vaporized form of the dopant. The diffused dopant is then driven further into the wafers with higher temperatures, and the wafer surface is reoxidized. Until 1970, diffusion was the only doping procedure in use. As the sophistication of semiconductor devices increased, however, a technique that would allow for cleaner, more controlled doping was needed, and ion implantation came into use. In this method, the dopant atoms are given a charge and accelerated to a high speed. The ions bombard the wafer surface where it is exposed through a blocking mask. The temperature of the wafer is then increased in order to diffuse the impurities deeper into the silicon.

Next, an additional layer of photoresist is applied, and the masking and etching processes are repeated, uncovering areas of the doped silicon. The hardened photoresist is dissolved, and, in the final masking stage, aluminum strips are added, completing the transistor.

For most integrated circuit devices, ten to twenty masks are required; for complex circuits, nearly 100 masks are used. Each new pattern is aligned precisely with those already on the wafer. Given the tiny size of the features of the patterns, it is easy to see that the allowable margins of error in alignment are minute as well.

Often, the layers of a wafer require some protection against moisture and contamination. In the passivation step, an inorganic coating, usually of silicon dioxide or silicon nitride, is applied. Next, in the metallization, or deposition, step, thin metal films are applied to certain areas of the silicon chip. The metal is used to connect the various transistors, diodes, and other components on the integrated circuit.

Once the metal contacts are established, the devices can be tested for low-power characteristics and the functioning of most integrated circuits can be checked. At this point, the wafer will contain hundreds of discrete devices. Computer-controlled equipment is used for the testing, and defective devices are marked and discarded later. Finally, individual chips, or dice, are separated from the wafer. In the dicing process, either a high-powered laser beam or a diamond-pointed saw is used.

The focus of our study is the equipment used only in the "front end" processes, starting with the lithography stage and ending just before the testing, dicing and assembly steps. Worldwide sales of the equipment included in our study totalled about $4.5 billion in 1989. We will now discuss more fully the different types of equipment used in these front end processes.

B. PRODUCT DESCRIPTIONS

1. MICROLITHOGRAPHY

Microlithography equipment can be considered the most important machinery in the semiconductor manufacturing process. The accuracies involved in the correct exposure of the patterns and alignment of the masks, as well as the demand for contamination-free production, have led to a high degree of automation in this process. The microlithography market accounts for about 25 percent of the total world market for wafer fabrication equipment.

Several different techniques are used to transfer the desired patterns to the wafers. In the **contact/proximity method**, the pattern on the mask is the same size (or very nearly so) as it will appear on the photoresist. The wafer is held in contact or near-contact (proximity) with the mask. While the resolution of the pattern is usually excellent with this method, there is always the danger that a particle on the wafer will get crushed against the mask, ruining the mask and, therefore, all subsequent wafer exposures. In the **projection alignment method**, the mask and the wafer never touch, thereby preventing damage to both the mask and the photoresist. With this system, the pattern on the mask is projected onto a mirror, then reflected onto the wafer. The cost of projection exposure is about five times that of contact aligner systems. The cost increases are partially recovered through increased yeild. However, projection alignment method is subject to mask defects, misalignment, and light variations.

Because of the problems with the projection and contact/proximity techniques, they have been largely replaced by the **step and repeat method**. The equipment used in this method, called optical wafer steppers, represented 80 percent of world sales of microlithography equipment in 1989. In this technique, the reticle, which is the pattern normally used to produce the mask, is instead projected directly onto one area of the wafer, exposing the photoresist. It is then moved, or stepped, to another area, and the process is repeated. The advantage of this method is accuracy: a single reticle can be reproduced with greater accuracy than can a mask that exposes the entire wafer. That mask is composed of multiple reticles.

Another option for lithography is electron beam, or **E-beam, direct writing**. With this method, the pattern is written directly on the wafer using an electron beam; no mask is required. The pattern is stored in the memory of the E-beam exposure machine, which controls the E-beam. The advantage of this method is the very small resolution that is possible; however, the cost of such a system is high, and the productivity, in terms of wafers per hour, is low, relative to other techniques. A related method is **focused ion beam technology**. This is similar to E-beam technology except that an ion source is used rather than electrons. With E-beam technology, the electrons are scattered through the photoresist, and this is a limitation in submicron applications. Ions are much heavier than electrons and do not scatter so easily.

X-ray lithography is being developed in response to the conventional wisdom that optical lithography using ultraviolet light will not be effective as geometries go below 0.25 to 0.3 micrometers. Since x-ray wavelengths are shorter than those of ultraviolet or visible light, x-rays can be used to draw much finer features, which will make it possible to store much more information on a single chip.

Another important aspect of microlithography is **mask making.** In the mask making step, the circuit design is transferred to the mask. To accomplish this, the design is stored in a computer and reproduced on an emulsion or chrome photo plate, called a reticle. The pattern on the reticle is transferred to a photoresist-coated mask blank usitng a step and repeat method similar to that used later in writing the pattern onto the wafer itself. An alternate method, using E-beam technology, transfers the design stroed in the computer directly to the mask blank. No reticle is produced, eliminating one possible source of error. In either case, the completed mask is then used to transfer the pattern to the wafer through one of the methods discussed above.

2. DEPOSITION

Sales of deposition equipment account for about 30 percent of the total world market for wafer fabrication equipment. In deposition, a thin film of material is set down on the surface of a wafer. The layers of film become the wires and insulators that, eventually, form the interconnections crucial to the functioning of the transistor. **Chemical vapor deposition (CVD)** is the predominant method in use. In this technique, known chemical reactions are used to deposit thin films. **Epitaxial deposition** is a special form of CVD. In this method, additional single crystal silicon is "grown" above the original surface of the wafer. **Physical vapor deposition (PVD)** is another method used to metallize the wafer. It can be likened to sandblasting; under a very high vacuum, material is removed from a target by vaporization and adheres to the wafer, creating the film cover. Early forms of PVD involved the use of electron beams to vaporize the target. Electrons were adequate as long as the materials being deposited were pure metals. As the dimensions involved continued to shrink, alloys replaced pure metals, and sputtering replaced the electron beam methods of deposition. In **sputter deposition**, the target is vaporized with ions, rather than electrons.

3. ETCH & STRIP

Sales of etch & strip equipment account for about 20 percent of the total world market for wafer fabrication equipment. The equipment used at this phase in the semiconductor production process includes wet etch, plasma etch and reactive ion etch. The **wet etching method** was the first developed, and is still in use. In this method, chemicals in the etchant react with the layer being etched, combining with it to form a compound that can be rinsed away with water. The equipment required consists mainly of workstations containing sinks, exhaust hoods, temperature controls and wafer feeding mechanisms.

In the early eighties, **dry plasma etch techniques** largely displaced wet processing, due in part to shrinking line-width requirements. With this method, gases are used to create a plasma on the wafer surface which will reduce the photoresist to an ash; the ash is then pumped away from the wafer. One variant of dry plasma etching is **reactive ion etching**, or **RIE**. The etchant gas is ionized and its molecules accelerate to the surface of the wafer. The top layer of the wafer is then removed by physical means and by way of the chemical reaction that occurs. RIE is a very controllable technique, and it is also quite productive.

4. ION IMPLANTATION

Ion implantation equipment represents from 10-15 percent of the total world wafer process equipment market. These machines inject dopants into semiconductor wafers by accelerating a beam of ionized atoms through electric fields of several thousand volts, ranging from 20,000 to more than 200,000 electron volts; the molecules gather enough energy to penetrate the silicon surface of the wafer.

Ion implantation equipment can be broken into two categories: **current** and **high voltage**. Current implanters can be further broken down into low-to-medium and high current machines. The higher the current, the shorter the time required for implantation. Low-to-medium current is appropriate for light doping, while high current is used for heavy doping. High voltage implanters have the ability to implant the dopants very deeply; recent innovations in semiconductors make this desirable.

5. THERMAL PROCESSES

This sector of the equipment market accounts for less than 10 percent of the total world market for wafer fabrication equipment. The machinery used in thermal processes includes **diffusion/oxidation furnaces** and **rapid thermal processing (RTP) equipment.** Diffusion furnaces introduce the dopants onto the wafer, and oxidation furnaces are used both to grow oxide films and further diffuse the dopant after it is applied. RTP equipment repairs damage done to the crystal lattice during ion implantation, and it also activates dopant atoms.

C. GLOBAL INDUSTRY OVERVIEW

More than 200 companies worldwide compete in the wafer fabrication equipment market; almost all are based in the United States, Japan and Europe. In addition, some other countries are striving to develop indigenous capability to manufacture semiconductor producing equipment. South Korea, for example, has a complex plan to develop its semiconductor equipment industry in order to counter overdependence of Korean semiconductor producers on foreign equipment.

Major suppliers, by country, are listed below. While there are less than 20 Japanese and less than 10 European producers, over 100 U.S. firms serve this market. The majority of U.S. firms are small, niche producers, with sales of between $5 and $25 million. Only a few have a strong position in the world market, with sales of $200 million or above. Market share is concentrated among a few large companies, mainly because the costs of doing business are very high.

SALES

Worldwide sales of all semiconductor manufacturing equipment (both front and back erd) nearly quadrupled between 1980 and 1988, growing from almost $2.1 billion in 1980 to nearly $8.3 billion in 1988. During the same time period, the U.S. share of these sales dropped dramatically from 75 percent to 49 percent, while Japan's share more than doubled, growing from 18 percent to 39 percent (see graph). The shift in market leadership is especially apparent for lithography equipment, test equipment, and materials.

MAJOR SUPPLIERS OF WAFER PROCESSING EQUIPMENT

UNITED STATES

Applied Materials - *Ion Implant, Deposition, Etching*
BTU International - *Thermal Processes*
Eaton - *All Product Types*
FSI International - *Etching*
General Signal - *Lithography, Thermal, Deposition, Etching*
Genus - *Ion Implant, Deposition*
Lam Research - *Deposition, Etching*
Novellus - *Deposition*
Silicon Valley - *Lithography, Thermal, Deposition, Etching*
Varian - *Thermal, Ion Implant, Deposition, Etching*

JAPAN

Anelva - *Deposition, Etching*
Canon - *Lithography, Etching*
Dainippon Screen - *Lithography, Thermal Processes, Etching*
Hitachi - *Lithography, Ion Implant, Deposition, Etching*
JEOL - *Lithography*
Kokusai Electric - *Thermal, Deposition, Etching*
Nikon - *Lithography*
Nissin Electric - *Ion Implant*
Sony/MRC - *Deposition, Etching*
Tokyo Electron - *All Product Types*
Ulvac - *Thermal, Deposition, Ion Implant, Etching*

EUROPE

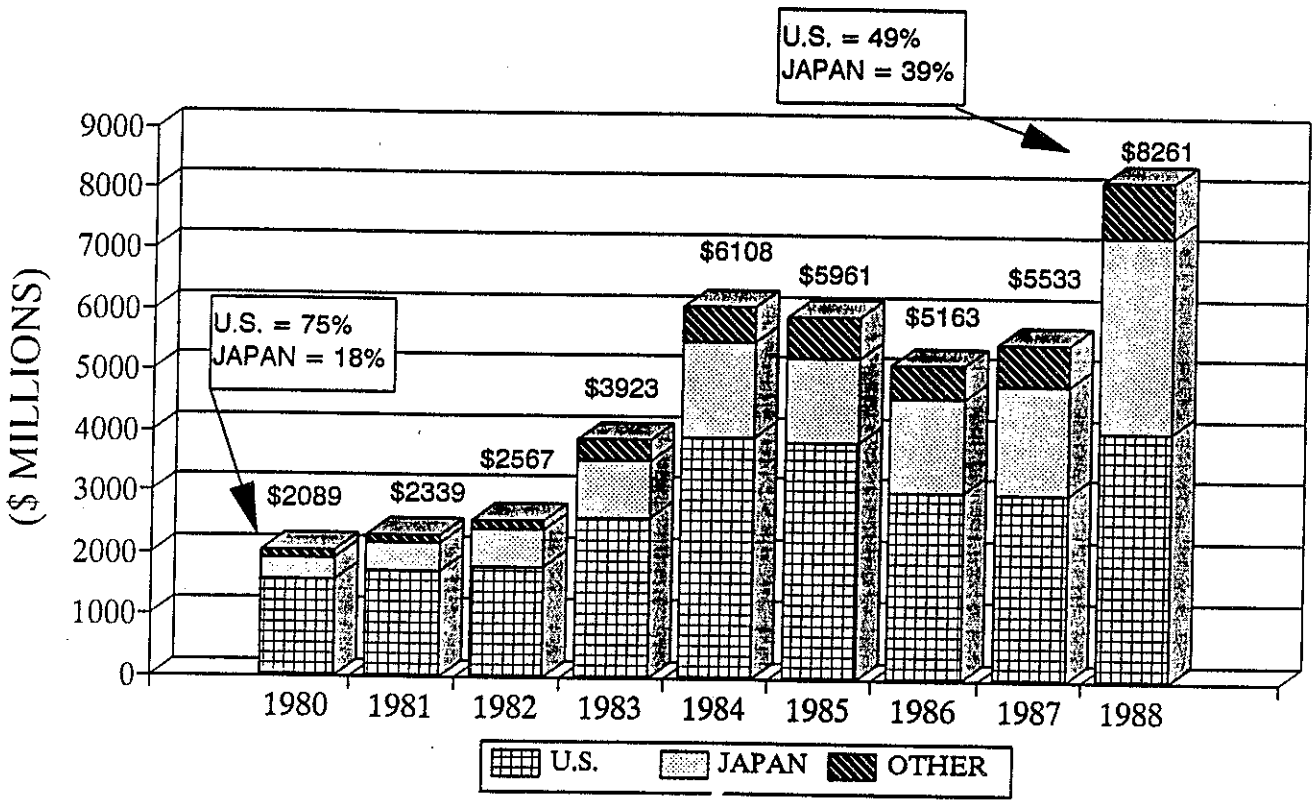
ASM - *Thermal Processes, Deposition*
ASM Lithography - *Lithography*
Balzers - *Ion Implant, Deposition, Etching*
Cambridge Instruments - *Lithography, Deposition*
Leybold-Heraeus - *Deposition*
Riber - *Deposition*

In 1979, the nine largest semiconductor manufacturing equipment suppliers, in terms of sales, were U.S. firms. No Japanese firms were in the top ten. By 1988, Japanese firms held the top three spots, as well as the sixth spot.

CONSUMPTION

In 1980, U.S. consumption of front and back end SME was nearly double that of Japan; the U.S. market accounted for 58 percent of world consumption, while Japan made up just over 29 percent of world consumption. By 1988, Japan's consumption had surpassed that of the United States, and the trend continues with no sign of reversal. This pattern is not surprising, given the relative decline in the U.S. semiconductor production market and the parallel growth of semiconductor production and demand in Japan.

SEMICONDUCTOR MANUFACTURING EQUIPMENT
SALES BY COUNTRY OF ORIGIN



NOTE: THESE DATA INCLUDE SALES OF BOTH FRONT AND BACK END EQUIPMENT.
SOURCE: VLSI RESEARCH

SECTOR ANALYSIS[1]

This section provides a detailed analysis for each of the major subsectors of the wafer processing equipment industry. As will become evident, most companies specialize and do not compete in all five market sectors. U.S. companies have fared differently in each of the sectors over the past five years. Therefore, examining just the total wafer processing equipment industry does not present a complete picture of important trends in subsectors.

A. MICROLITHOGRAPHY

Of all wafer processing equipment, microlithography equipment is at the very heart of integrated circuit manufacture. Microlithography equipment and improvements in it are key to improvements in integrated circuits themselves. This equipment has by far the most stringent precision requirements in the wafer processing industry. As the industry has evolved over the past three decades, only a limited number of companies have been able to sustain development efforts needed to produce machines that are capable of sub-micron precision.

There are basically two types of microlithography equipment: **optical aligners** and **direct exposure.** The **optical alignment** category, which accounts for over 90 percent of microlithography equipment, includes contact/proximity aligners, scanning projection aligners, stepper aligners, and x-ray aligners.

At present, the most common type of microlithography equipment (accounting for about 80 percent of total world microlithography sales, or about $1 billion) is stepper aligners, also known as step and repeat equipment. These systems, first sold in 1976, gradually replaced earlier forms of wafer exposure equipment, such as contact and proximity aligners and scan/projection aligners. Steppers are particularly useful in high-volume merchant integrated circuit manufacturing lines.

X-ray lithography offers some advantages over lithography methods using visible light, namely, increased accuracy. Unfortunately, the equipment needed to generate the x-rays and the special masks

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[1]This section draws heavily from data compiled by VLSI Research, Inc., a market research firm based in San Jose, California, that specializes in this equipment.

and photoresists required are expensive. And, x-ray aligners, still in their infancy, have not yet achieved submicron capabilities, and account for less than 5 percent of aligner sales.

Direct exposure lithography equipment, which accounts for the remaining portion of the microlithography business, includes E-beam, laser and ion-beam direct writers. E-beam is the most commercialized of these types, and while very expensive, allows highly customized manufacturing for such items as Application Specific Integrated Circuits (ASICs). World sales of E-beam equipment in 1989 totalled $63 million.

The table below illustrates the worldwide stepper/aligner market for 1984-1989. Some trends are readily apparent.

WORLD MARKET SHARE BY COMPANY AND COUNTRY
OPTICAL WAFER STEPPERS

COMPANY	1984	1985	1986	1987	1988	1989
Nikon	32%	30%	33%	39%	49%	46%
Canon	3%	12%	16%	18%	19%	21%
Hitachi	4%	4%	4%	7%	4%	7%
Total Japan	**39%**	**46%**	**53%**	**64%**	**72%**	**74%**
G.C.A/Gen'l Signal*	48%	38%	31%	22%	19%	11%
Eaton	6%	5%	1%	0%	(Exited Market)	
Perkin/Elmer(SVG)*	3%	6%	9%	4%	2%	3%
ASET	2%	2%	3%	2%	1%	1%
Total U.S.	**59%**	**51%**	**44%**	**28%**	**22%**	**15%**
ASM	1%	1%	2%	6%	6%	10%
Total Europe	**1%**	**1%**	**2%**	**6%**	**6%**	**10%**
TOTAL VALUE (Millions)	$446	$348	$316	$431	$840	$997

Source: Compiled from VLSI Research data

*General Signal acquired G.C.A. in June, 1988. This is the combined market share. Silicon Valley Group bought Perkin-Elmer's optical lithography division in 1989.

The years 1985 and 1986 were a period of retraction for the wafer manufacturing equipment industry, leading to a recovery in 1987 and strong growth in 1988-1989. The table shows a continued increase in world market share by Japanese firms, particularly Nikon and Canon. Even during the downturn of the mid-eighties, Japanese firms were able to expand their market share, primarily at the expense of U.S. firms. In 1989, Japanese firms supplied nearly three-quarters of the world market for steppers. ASM, a Dutch firm jointly owned by N.V. Philips and the government of the Netherlands, also showed strong performance during the period.

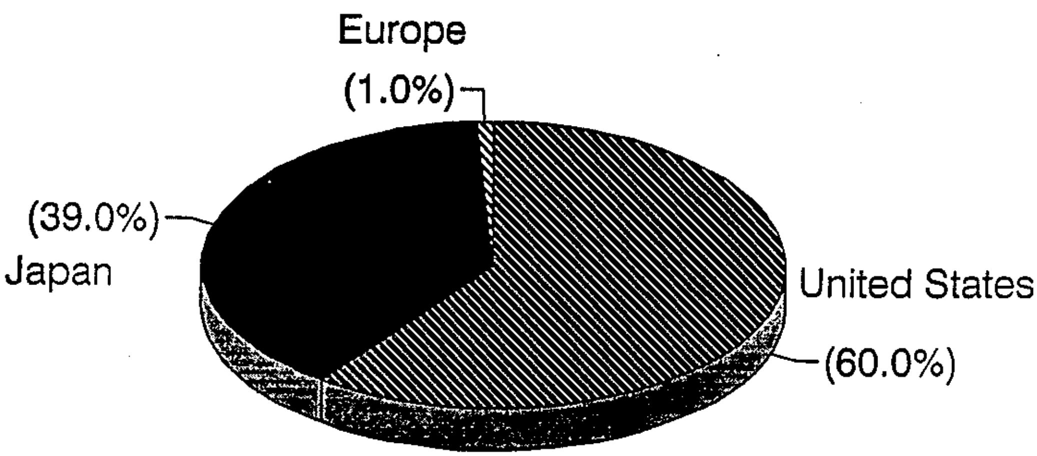
In contrast, U.S. firms consistently lost market share even though they may have experienced increased sales in both units and value over the period. This is possible because the size of the stepper market has increased steadily, from $431 million in 1987 to about $1 billion in 1989. As recently as 1984, U.S. firms (primarily General Signal and GCA) accounted for about 60 percent of world stepper sales, while Nikon represented 32 percent of sales and other Japanese firms, an additional 7 percent.

One of the major reasons Japanese firms, particularly Nikon, were able to expand market share so quickly is technology innovation. Nikon, with the support of its government, developed a stepper in the early 1980s that "leapfrogged" the stepper technologies that U.S. firms were offering. U.S. firms have since made a technological comeback, but have failed to regain lost market share.

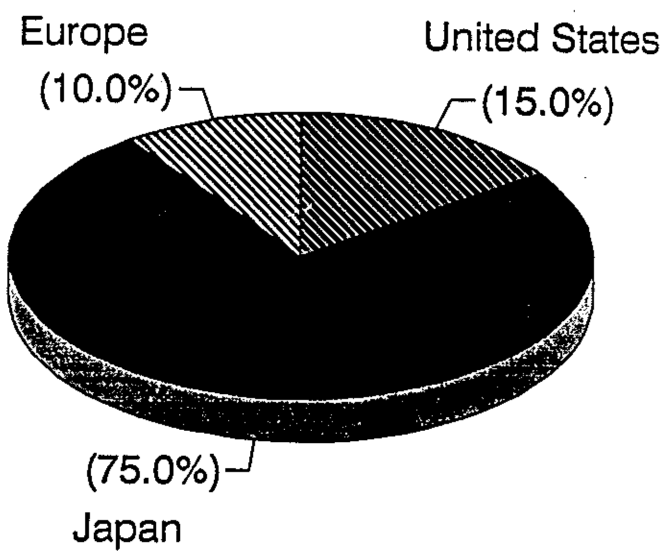
Company sales by consuming country were also analyzed. Of the major U.S. stepper suppliers, only GCA/General Signal was able to penetrate the Japanese market, selling 5 units in 1987 (about 2 percent of Japanese stepper consumption). In 1988 and 1989, General Signal sold 3 and 4 units in Japan, respectively, but since the market had expanded greatly, this represented less than 1 percent of their consumption.

On the other hand, certain Japanese companies have captured a significant share of the U.S. market. While Hitachi, the third largest Japanese manufacturer, does not yet participate in the U.S. market, Nikon and Canon have become powerful players.

WORLD MARKETSHARE BY REGION
WAFER STEPPERS



1984: Total Sales $446 Million



1989: Total Sales $997 Million

Together, they accounted for over 45 percent of U.S. consumption in 1989, up from 40 percent in 1987.

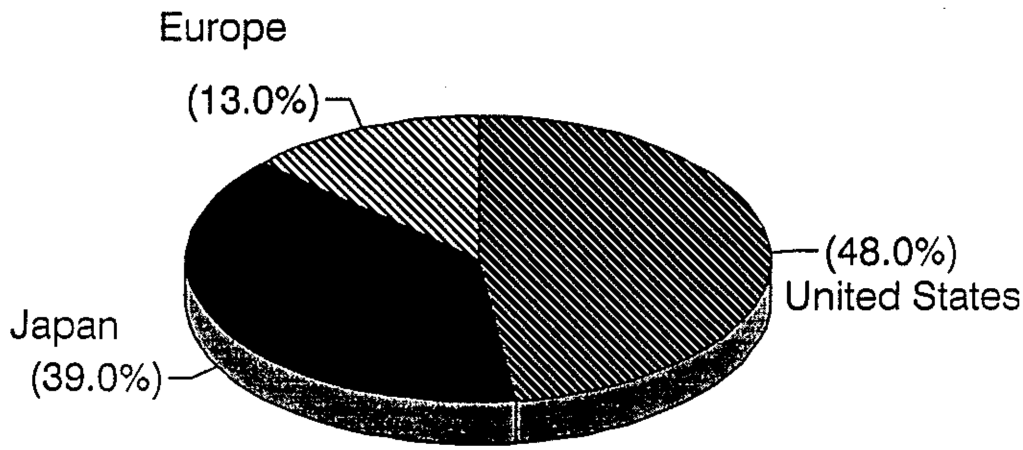
Less information is available about the other types of microlithography equipment. World sales of scanning/projecting equipment in 1989 were $109 million, for which Canon had about 60 percent of the market, and Silicon Valley Group the remainder. Five companies competed in the E-beam market in 1989, with JEOL and Hitachi of Japan leading, each with about 25 percent of the $63 million market. Other significant players were Cambridge Instruments of the United Kingdom (22 percent), ETEC (formerly a division of Perkin-Elmer, 19 percent) and ASM of the Netherlands (4 percent).

B. THERMAL PROCESSES

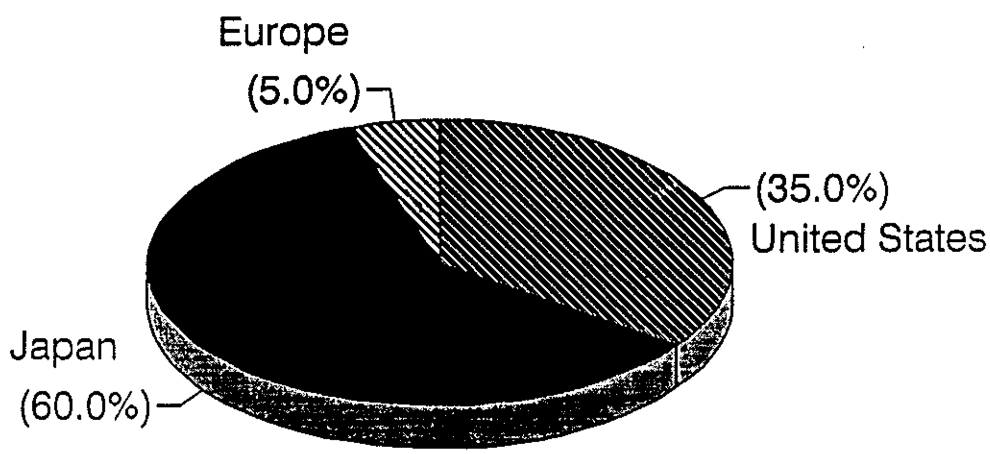
This market segment includes **diffusion furnaces, oxidation furnaces**, and **rapid thermal processing equipment.** This segment of the wafer processing industry has matured in terms of technology, but incremental improvements continue to be made in equipment leading to increases in productivity and reduced costs for integrated circuit manufacturers. Sales of thermal processing equipment totalled $343 million in 1989; almost 90 percent of this was diffusion furnaces.

In the **diffusion** sector, Tokyo Electron (TEL) of Japan captured about 40 percent of the market, up only slightly over its market share in 1984. Kokusai Electric, the second largest supplier, accounted for an additional 17 percent market share, and several other Japanese firms brought that country's share to 60 percent of the world market, up from 39 percent in 1984. U.S. firms, led by the Silicon Valley Group with a 16 percent market share, accounted for 35 percent of the world market. Other major U.S. suppliers include BTU International (10 percent share) and General Signal (4 percent share). The total U.S. share is down from 48 percent in 1984. The remaining 5 percent of the market in 1989 is accounted for by European firms, primarily ASM. Sales of thermal processing equipment followed the same pattern as that for microlithography equipment over the 1984-1989 period, with sales bottoming out in 1987 at about $130 million. The sector rebounded to almost $350 million in 1989.

WORLD MARKETSHARE BY REGION
DIFFUSION EQUIPMENT



1984



1989: Total Sales $343 Million

C. DEPOSITION

Deposition, the process of laying down a film of material (metals, silicides, etc.) on the surface of a wafer is, along with microlithography, an important technology driving the semiconductor industry. The importance of deposition has increased in recent years; it was the fastest growing sector of the industry in the 1980s.

As discussed in the Industry Overview, there are three categories of deposition: **chemical vapor deposition** (CVD), **physical vapor deposition** (PVD) and **epitaxy**. In 1989, CVD, the largest and fastest growing segment, accounted for slightly over half of the total deposition market ($621 million out of $1.1 billion). PVD accounted for an additional 30 percent, and epitaxy the remainder. The deposition industry segment has been characterized by rapid shifts in technology by individual firms, and hence in changes in market positions.

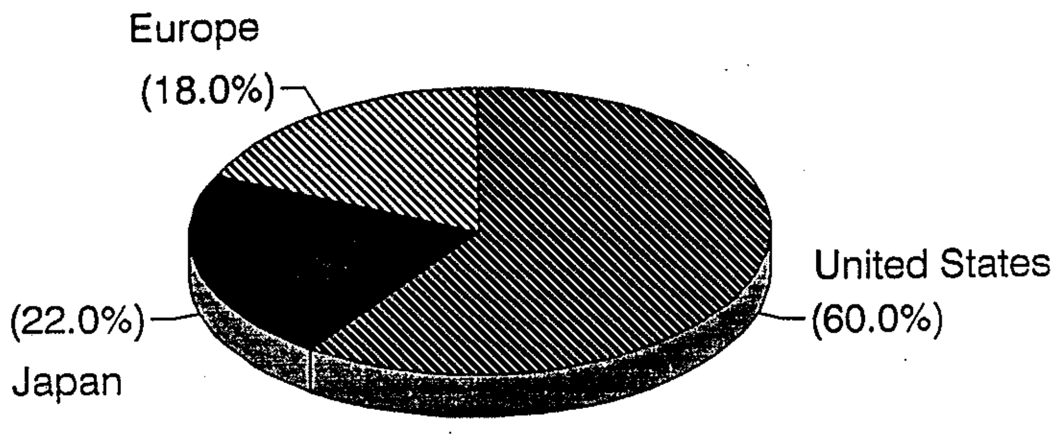
1. CVD

In 1989, U.S.-based Applied Materials was the market leader in chemical vapor deposition equipment, with over a quarter of world sales. European-based ASM had an additional 13 percent share. Two additional U.S. firms, Genus and Novellus, had significant market shares (9 percent and 7 percent, respectively). The remainder of the market is shared by a large number of firms. Unlike microlithography and other sectors of the wafer processing equipment industry, Japanese firms do not yet have a particularly strong presence in this category. The largest Japanese supplier is Tokyo Electron, with a 7 percent share, followed by Kokusai Electric, with a 6 percent share. Overall, U.S. suppliers accounted for 60 percent of the world market, Japanese suppliers about 22 percent, and Europe, about 18 percent.

2. PVD

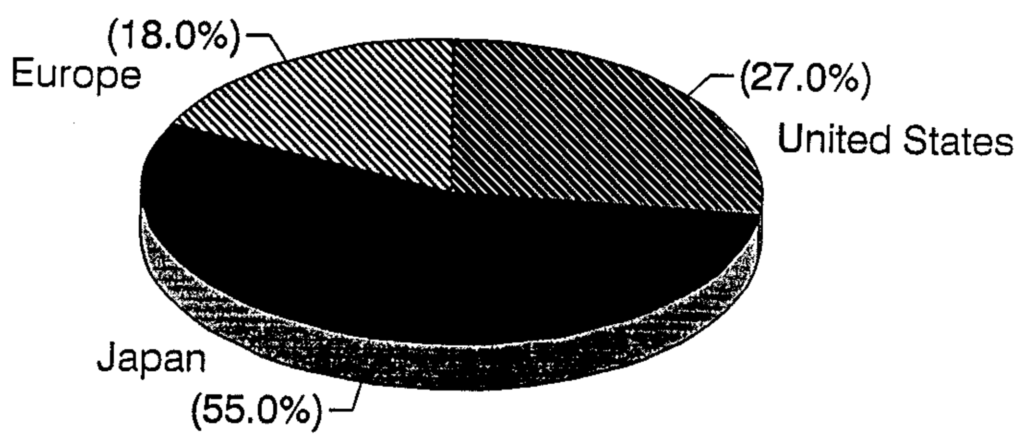
Physical vapor deposition (PVD) equipment accounted for about $350 million in sales in 1989, most of which was conventional sputtering equipment. The market leader in this subcategory was Sony/MRC, with a 21 percent share, followed closely by Varian, with a 20 percent share. Other major players were two Japan-based firms, Ulvac and Anelva, with roughly 15 percent each. Overall in the PVD market, Japan-based firms (including Sony/MRC) captured 55 percent of the market; U.S. firms accounted for

WORLD MARKETSHARE BY REGION
CHEMICAL VAPOR DEPOSITION



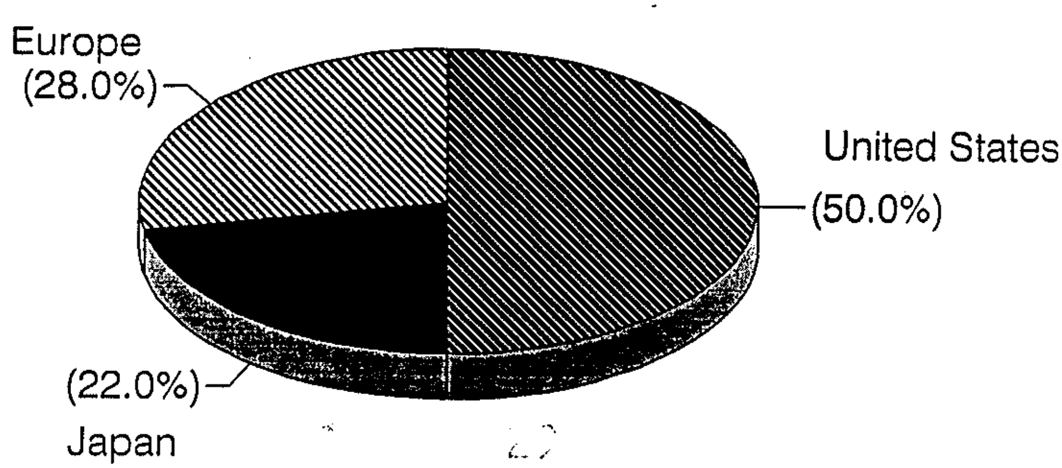
1989: Total Sales $621 Million

PHYSICAL VAPOR DEPOSITION



1989: Total Sales $350 Million

EPITAXY



1989: Total Sales $166 Million

27 percent; and European firms (including Balzers and Leybold-Heraeus), 18 percent.

3. Epitaxy

Epitaxy is the smallest segment of the deposition equipment market with total world sales of $166 million in 1989. The largest single supplier was Lam Research, a U.S. firm that specializes in silicon epitaxy **technology**. Lam had about 15 percent of the world market; nonetheless, Lam decided to exit this market in 1990. The second largest supplier was Riber of France, with about 12 percent of the market, followed by Varian, with a 9 percent market share.[2] The largest Japanese suppliers were Ulvac with 6 percent and Kokusai Electric with a 5 percent share. Overall, U.S. firms maintained a 50 percent market share, Japanese firms totalled about 22 percent market share, with the remaining 28 percent split among European suppliers, including Riber, ASM, VG Semiconductor and Cambridge Instruments. The epitaxy market grew at a slow pace over the years 1985-1989, in contrast to some other processing equipment sectors, which experienced strong growth in recent years.

D. ION IMPLANTERS

The **ion implant equipment** market was $564 million in 1989, up from $395 million in 1988. Of the total, about two-thirds were high-current ion implanters. **Low-current ion implanters** accounted for about 25 percent of the total, and **high voltage ion implanters** for 6 percent. Companies generally compete in both the high and low current markets, while different firms participate in the high voltage market.

Overall, the market leader in ion implanters is Varian, with about a 30 percent market share. Varian is particularly strong in low current equipment. Eaton, the runner-up with an overall 19 percent market share, participates in all three market segments. Tokyo Electron, competing in the current segments

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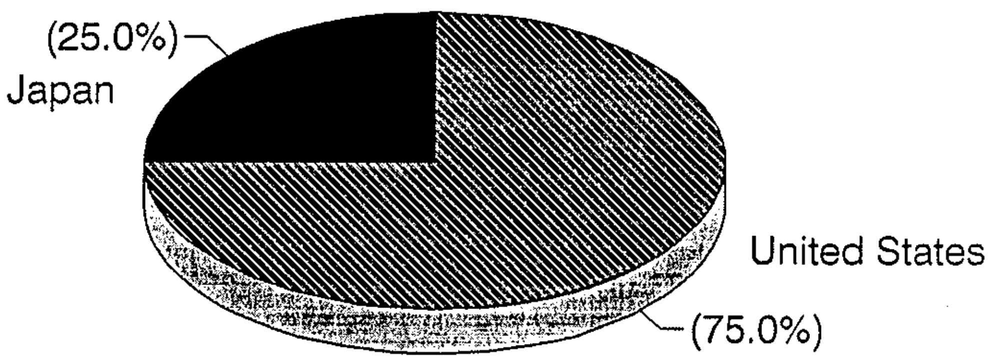
[2]Instruments S.A. of France (parent company of Riber) acquired Varian's molecular beam epitaxy division in early 1991. With the completion of this transaction, the U.S. share of the world molecular beam epitaxy market will decline to less than 5 percent, while the European share will increase to about 36 percent, assuming that Applied Materials absorbs all of the market share available after Lam Research's exit from the silicon epitaxy segment.

WORLD MARKETSHARE BY REGION
ION IMPLANTERS



1989: Total Sales $564 Million

only, accounts for about 16 percent of the total market. Applied Materials has an overall 11 percent market share, but is a fairly

SHARES OF THE WORLD ION IMPLANT MARKET
BY COMPANY AND COUNTRY
1989

Varian Associates	U.S.	30%
Eaton	U.S.	19%
Tokyo Electron	Japan	16%
Applied Materials	U.S.	11%
Nissin Electric	Japan	5%
Genus	U.S.	3%

Source: VLSI Research

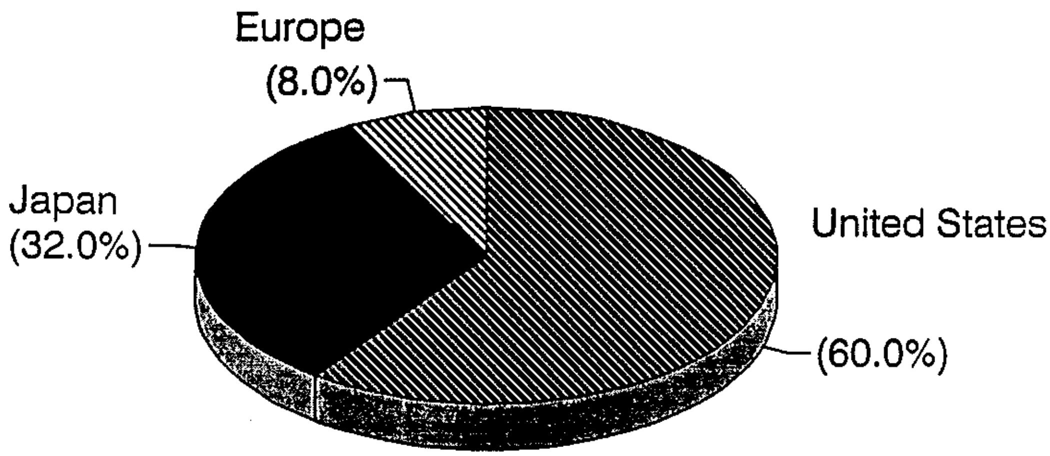
strong competitor in the high current segment. Nissin Electric has an overall 5 percent market share, and Genus has 3 percent; it should be noted, however, that Genus is the market leader in high voltage equipment, with well over half of that small market. In conclusion, U.S. firms continue to dominate the world ion implantation market, with approximately three-quarters of sales. Japanese firms account for most of the remaining 25 percent.

E. ETCHING

The **etching equipment** market is commonly divided into two segments: **wet etching** and **dry etching.** Worldwide sales of etching equipment totalled $874 million in 1989, of which $724 (over 80 percent) was dry processing, including plasma etching, ion etching, and dry stripping. Like other sectors of the wafer processing equipment industry, etching equipment sales grew strongly between 1987 and 1989, after experiencing contraction in 1986 and slow growth in 1984 and 1985.

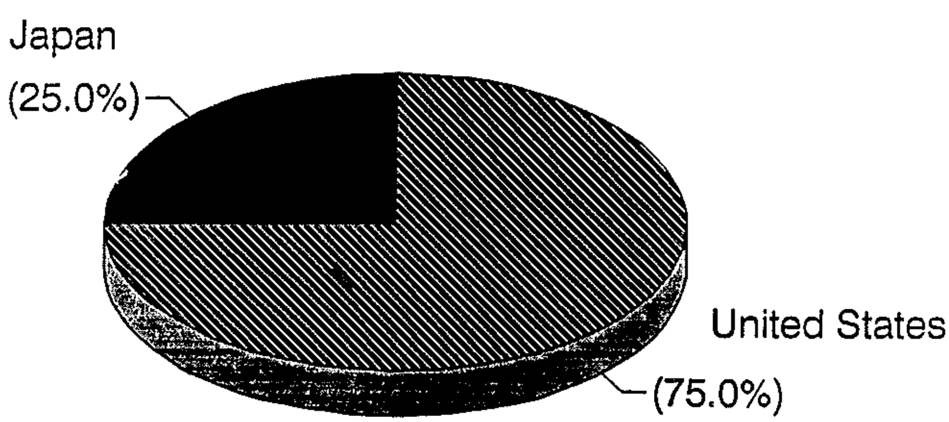
The dry etching equipment market was led by Applied Materials, with a 26 percent share. Tokyo Electron was second, followed closely by Lam Industries, with roughly 13 percent market share each. Tegal maintained a 7 percent market share in 1989, and General Signal, a 4 percent share. Overall, U.S. firms held approximately 60 percent of the market, Japanese firms, 32 percent, and Europeans, the remainder. In 1984, the U.S. share was about 70 percent, and Japan's, 25 percent. Most of the gain accrued to Tokyo Electron, at the expense of U.S. firms Tegal (down from 19 percent share in 1984) and Applied Materials (which had a 37 percent share in 1984).

WORLD MARKETSHARE BY REGION
DRY ETCHING



1989: Total Sales $724 Million

WET ETCHING



1989: Total Sales $150 Million

In the much smaller and stagnant wet etching equipment market, the undisputed market leader is U.S.-based FSI International, with 26 percent of the market. Other major players are Dainippon Screen of Japan (20 percent), U.S.-based SCP Manufacturing (10 percent) and Integrated Air Systems (7 percent). Overall, U.S. firms control 75 percent of the market, down only slightly since 1984. Japanese firms control the remainder.

F. SECTOR SUMMARY

The table below provides a summary snapshot of the relative shares of U.S., Japanese, and European firms in the various wafer processing equipment market sectors in 1989.

RELATIVE MARKET SHARES
BY PRODUCT SECTOR

Product Category	World Market $ Millions 1989	Japanese Mktshare %	U.S. Mktshare %	European Mktshare %
Optical Steppers	$ 997	74%	15%	10%
Diffusion Furnaces	$ 343	60%	35%	5%
Deposition	$1137			
C.V.D.	$ 621	22%	60%	18%
P.V.D.	$ 350	55%	27%	18%
Epitaxy	$ 166	22%	58%	20%
Ion Implant	$ 564	25%	75%	--
Etching	$ 874			
Dry	$ 724	32%	60%	8%
Wet	$ 150	25%	75%	--
OVERALL	$3915	44%	46%	10%

Source: Compiled from VLSI Research Data

The largest single equipment market, optical steppers, is the category in which the U.S. industry has experienced the greatest decline in market share. As explained earlier, this is probably the most critical type of equipment driving technological improvements; therefore, the loss of U.S. market share is a cause for concern from economic and national security perspectives. Other sectors in which the U.S. industry has lost most of the market include diffusion furnaces and physical vapor deposition. U.S. firms remain strong in the ion implant and etching/stripping sectors, but these sectors, too, have shown increased foreign competition in the past several years.

INDUSTRY PERFORMANCE

This section presents data on common industrial performance measures for nine companies, based on the Office of Industrial Resource Administration (OIRA) industry survey. When possible, data are also presented on the overall U.S. industry for comparison purposes.

A. SHIPMENTS & EXPORTS

The table below exhibits shipments, in units and dollars, for the surveyed firms. The companies were selected to represent a wide cross-section of the industry. Thus, shipments are included for most product categories, but do not represent the entire wafer processing industry.

Our best estimate, based on VLSI Research data, is that the OIRA survey covers about 25 percent of the U.S. wafer processing industry overall by dollar value of sales. In some product categories, however, OIRA data is more comprehensive. For example, we estimate that the OIRA data covers about 40 percent of the stepper/aligner and thermal processing segments in the U.S., about 20 percent of the deposition shipments, and about a third of the ion implanter industry. On the other hand, some product categories are not represented in the OIRA survey, including etch/strip equipment. These data show that, like the broader industry, OIRA's survey group experienced a slump in dollar shipments which bottomed out in 1986. In units, the low point was 1987, when just 645 machines were shipped. By 1989, dollar shipments for the survey group recovered to and surpassed the levels of before the downturn. Unit shipments, while recovering somewhat, have not exceeded pre-downturn levels. This discrepancy may be partially explained by increases in the price of the equipment due to inflation and increasing technological sophistication over the five year period. However, it is important to note that despite improvements in shipment levels since the mid-1980s, U.S. firms continued to lose market share at home and abroad, especially to Japanese suppliers.

SURVEYED FIRMS'
SHIPMENTS OF WAFER PROCESSING EQUIPMENT
IN UNITS, 1985-1989

TYPE OF EQUIPMENT	1985	1986	1987	1988	1989
Microlithography					
Optical	94	45	52	79	68
Other*	30	27	26	19	29
Deposition	232	191	147	224	224
Ion Implant	226	49	35	95	129
Thermal Processes	745	394	385	428	499
TOTAL	1327	706	645	845	949

SURVEYED FIRMS
SHIPMENTS OF WAFER PROCESSING EQUIPMENT
IN MILLIONS OF DOLLARS, 1985-1989

TYPE OF EQUIPMENT	1985	1986	1987	1988	1989
Microlithography					
Optical	$ 51.7	$ 40.8	$ 50.1	$ 68.0	$ 62.4
Other*	80.8	85.6	72.3	56.0	61.9
Deposition	81.0	59.8	164.8	87.8	111.5
Ion Implant	125.0	48.4	41.8	86.9	153.6
Thermal Processes	49.9	28.1	37.9	45.4	55.4
Other/Parts	36.9	28.7	36.2	38.8	60.7
TOTAL	$425.1	$291.3	$403.2	$383.1	$505.5

* Includes direct exposure writers, mask makers, and mask repair systems.
Source: OIRA Industry Survey

Overall, the firms reported operating at only 42 percent of capacity in 1989. Individual responses ranged from 10 percent to 90 percent capacity utilization. The capacity utilization figures correspond with market share data discussed in the previous chapter. Those sectors, such as optical lithography and thermal processing (diffusion) equipment in which the U.S. has lost much market share are operating at the lowest levels of capacity utilization. In contrast, sectors in which U.S. firms remain predominant, such as ion implant, show a high level of utilization.

SURVEYED FIRMS'
AVERAGE CAPACITY UTILIZATION
BY PRODUCT CATEGORY: 1989

Microlithography	
Optical	30%
Other	42%
Deposition	42%
Ion Implant	90%
Thermal Processes	35%

Source: OIRA Industry Survey

The surveyed firms exported about 50 percent of their products, a much higher percentage than most U.S. manufacturing sectors. The biggest markets for such equipment, according to industry experts, are Japan and Western Europe. The percentage of exports varied considerably by product sector, indicating relative strengths and weaknesses of the U.S. industry. For example, over 80 percent of ion implant equipment was exported. On the other hand, less than 50 percent of optical microlithography and thermal processing equipment was exported; the U.S. industry has experienced the greatest loss of market share to foreign firms in these segments.

SURVEYED FIRMS'
PERCENTAGE OF TOTAL SHIPMENTS EXPORTED
(1989, Unit Basis)

Microlithography	
Optical	47%
Other	55%
Deposition	50%
Ion Implant	85%
Thermal Processes	43%
TOTAL	51%

Source: OIRA Industry Survey

The firms were also asked to break down their 1989 shipments by market segment -- military, industrial, commercial, or space. The overwhelming majority of shipments went, not unexpectedly, to industrial applications, followed by commercial applications. Defense and space each accounted for only about 1 percent of shipments. This does not mean that wafer processing equipment is not important for or used in defense or space applications, but rather that the firms supply their equipment to other manufacturers (i.e., chip makers), primarily in industrial/ commercial markets who in turn supply defense markets, rather than directly to the Department of Defense or NASA.

B. EMPLOYMENT

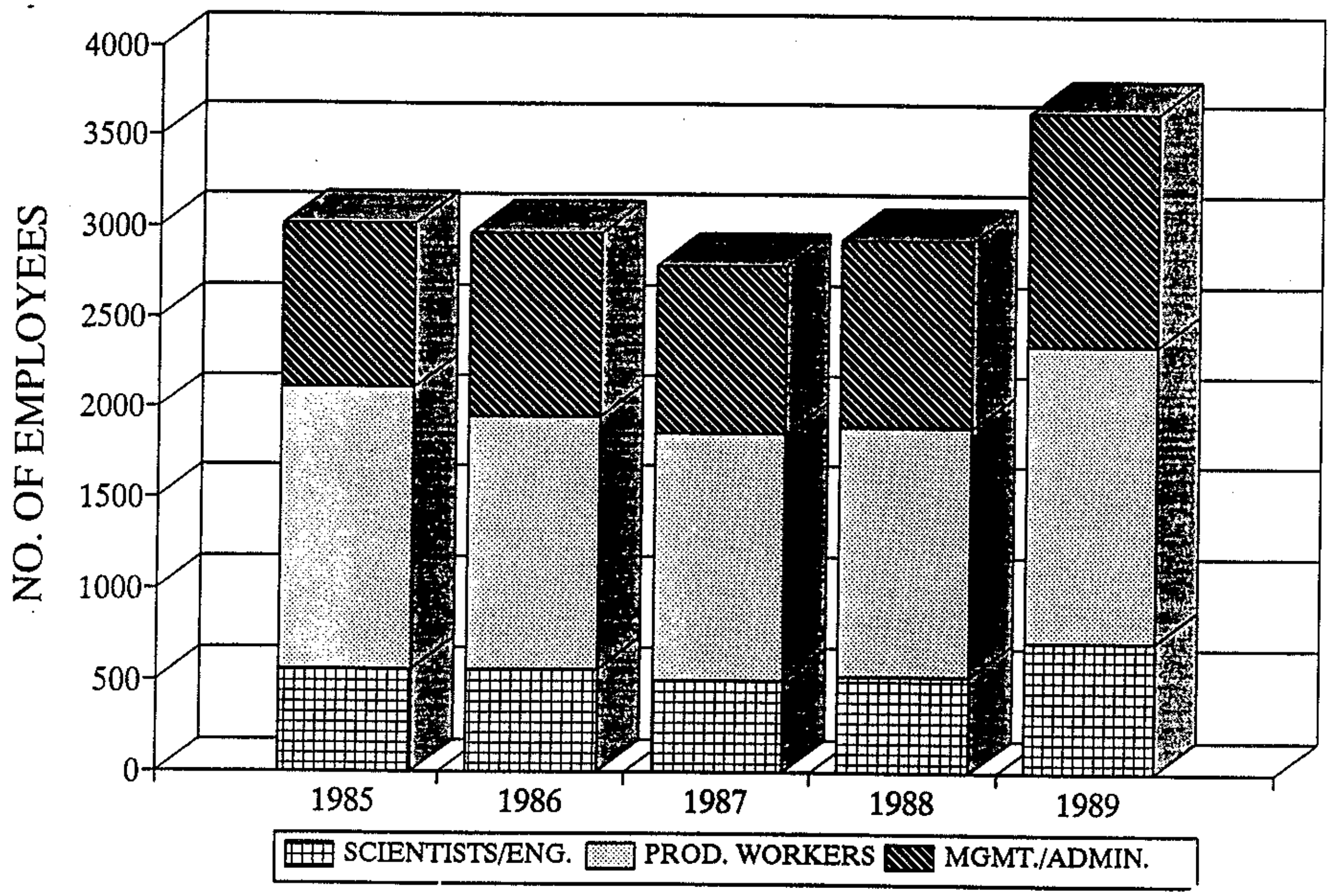
The chart below presents employment data for the nine firms surveyed. As expected, the employment data closely track shipment data, bottoming out in 1987, and then recovering and surpassing the level of 1985. One factor influencing the growth at the end of the period is an acquisition by one of the surveyed firms in 1989, which significantly increased its employment.

About 20 percent of employees were categorized by survey respondents as "scientists and engineers", a higher percentage than in most manufacturing sectors. This is an indication of the relative complexity of the equipment, as well as the importance to the industry of continued technological innovation. Individual company responses ranged from 13 percent to 35 percent for scientists and engineers in 1989. Production workers accounted for the bulk of employees, 45 percent, with a range of 20 percent to 90 percent. Management and administrative employees also accounted for a significant portion, 35 percent.

Survey recipients were also asked to comment on any labor-related problems they had encountered in the past five years that adversely affected manufacturing operations. Several firms cited labor shortages, particularly of skilled technicians and engineers, as a continuing problem. In addition, two firms mentioned labor turnover caused by financial difficulties resulting from foreign competition as a problem. Both of these firms were primarily in the microlithography business, which is the sector most affected by foreign competition.

The Bureau of the Census collects some further employment-related data for the semiconductor manufacturing equipment industry (SIC 35596), which includes most of the wafer processing industry. However, Census data exclude manufacturers of diffusion/ oxidation furnaces, and include manufacturers of assembly and packaging equipment. The Census information is useful for comparison purposes, nonetheless. According to the 1987 Census of Manufactures, the most recent available, there were a total of 9,200 employees in the SME industry, of which 3,500 (38 percent)

EMPLOYMENT
1985-1989



SOURCE: OIRA INDUSTRY SURVEY

were production workers. The average production worker loggesd about 1,950 hours per year, earning an average of $12.70 per hour. This figure compares favorably to hourly wages for overall U.S. manufacturing, which averaged just under $10.00 per hour in 1987.

C. RESEARCH & DEVELOPMENT AND INVESTMENT

1. Research & Development

The following table presents aggregated research and development (R&D) expenditures by the nine surveyed firms for the years 1985-1989.

As can be seen from the table below, the vast majority of R&D by the equipment manufacturers was funded in-house. R&D expenditures seem to be relatively constant from 1985 to 1988, ranging from $50 to $60 million per year. Even in the down years of 1986 and 1987, when shipments declined, surveyed firms maintained regular levels of R&D in the $50-$60 million range. For this reason, R&D as a percent of net sales was higher in those years. VLSI Research data for the larger wafer processing equipment industry indicate, however, that the percentage of net sales invested in R&D rather than actual dollars was constant over these years.

SURVEYED FIRMS'
RESEARCH & DEVELOPMENT
1985-1989
(Thousands of Dollars)

	1985	1986	1987	1988	1989
In-House*	$53,981	$60,118	$53,717	$52,946	$54,891
Government	0	0	0	1,753	4,447
Customer	151	0	500	1,740	5,555
Joint Venture	0	0	0	2,000	7,242
Other	0	0	500	0	600
TOTAL	$54,132	$60,118	$54,717	$58,439	$72,735
R&D as % of Net Sales	15.4%	24.3%	21.9%	16.4%	13.7%
R&D as % of Sales (VLSI Research Data)	16.0%	17.3%	16.6%	17.1%	NA

*Includes debt and equity capital
Source: OIRA Industry Survey

Although it would be premature to predict a trend, it is interesting that R&D expenditures increased sharply in 1989, to over $72 million. As can be seen from the table, this increase can be attributed to R&D funding in forms that were previously unconventional for this industry -- through the government, joint ventures, and customers. It appears that this trend began in 1988 and increased significantly in 1989, but it is too early to determine if it will continue in the future. The government funding may represent a response to the increasing economic and national security concerns regarding the long-term viability of the semiconductor manufacturing equipment industry. For the customer, joint venture and other funding categories, it may represent a recognition by these entities that the equipment manufacturers alone can no longer fund the R&D necessary to develop the "next generation" machines.

Firms surveyed spent approximately 15 to 20 percent of net sales on research and development. This is comparable to the average R&D expenditures for semiconductor manufacturing equipment producers as estimated by VLSI Research Inc., and significantly higher than average R&D expenditures for all manufacturing sectors (between 3 and 4 percent). This is an indication of the extremely high costs associated with developing semiconductor manufacturing equipment.

Among the individual firms there was significant variation in R&D expenditures as a percent of sales, ranging from less than 10 percent of net sales to over 40 percent. The figure for 1989, 13.7 percent, is somewhat lower than other years, despite the fact that, overall, that year represented the highest expenditure (more than $72 million). This can be explained by recalling that sales and shipments by the surveyed firms were sharply increased in 1989, largely due to significant increases by two or three firms. Since R&D expenditures can be expected to lag behind sales, one would anticipate that a greater percentage would be allocated to R&D in 1990.

Dataquest Inc., another market research firm, undertook a similar comparison of R&D to sales for several publicly-held wafer fabrication equipment manufacturers. Dataquest's average of 13.4 percent of 1989 sales for R&D expenditures is strikingly similar to the OIRA survey data. Dataquest also discovered that the companies that devoted the greatest percentage of sales for R&D had lower operating income than average, implying that companies must sacrifice short-term profits to invest in new product development in order to survive in this extremely competitive market.

The firms surveyed by OIRA were also asked to specify areas of research and development for 1989. Their responses are indicated below, along with the aggregate amount devoted to each particular area. These figures are heavily influenced by the largest firms surveyed, who are active in deposition. It is interesting that none of the firms surveyed indicated any R&D activity in the area of x-ray lithography; this area is widely believed to be the basis of the "next generation" lithography equipment, and Japanese and European firms, along with their governments, are devoting significant resources to further development of this technology. This may be partially explained by the limited number of firms in the OIRA survey.

SURVEYED FIRMS'
AREAS OF RESEARCH & DEVELOPMENT FOCUS
1989 Expenditures
(Thousands of Dollars)

Deposition (CVD, PVD)	$24,271
Implanter	$13,869
Optical Lithography	$9,423
Diffusion	$8,236
E-Beam Mask Maker	$6,908
E-Beam Direct	$4,388
Ion Beam	$2,241
Laser Technologies	$2,023
Laser Mask Maker	$1,376
X-ray Lithography	--
TOTAL	$72,735

Source: OIRA Industry Survey

2. Capital Investment in Plant and Equipment

In addition to expenditures to research and develop new products and processes, the nine surveyed firms also invested capital in facilities and equipment for manufacturing. The table below presents their aggregate investments in plant and equipment for the 1985-1989 period.

SURVEYED FIRMS'
CAPITAL INVESTMENT
(Millions of Dollars)

	1985	1986	1987	1988	1989
Plant	$11.6	$10.6	$ 7.0	$ 0.7	$ 1.3
New Machinery	14.1	16.0	8.7	8.8	9.9
Total	$25.8	$26.5	$15.7	$ 9.5	$11.2
Capital Investment as % of Net Sales	7.0%	10.7%	6.3%	2.7%	2.1%

Source: OIRA Industry Survey

The data show a generally declining trend of investment in both plant and new machinery. They also show a declining percentage of net sales devoted to investment, ranging from almost 11 percent in 1986 to just over 2 percent in 1989. This may be explained by the market slump of the mid-1980s which left the firms with little to spend on expansion or modernization of facilities. With the relatively short life cycle of wafer processing technology and increasing foreign competition, the firms apparently viewed it as more important to maintain R&D spending on new products and processes than on plant and equipment. Now that the slump has ended and the industry has sustained two years of growth, investment will likely increase as well. In fact, the 1989 figures show modest gains over 1988 levels.

D. FINANCIAL PERFORMANCE

Profitability data for eight of the wafer processing companies surveyed are presented in the table below.[3]

[3] One surveyed firm did not have financial data available for just the semiconductor equipment segment of operations.

SURVEYED FIRMS'
PROFITABILITY
(Millions of Dollars)

	1985	1986	1987	1988	1989
Net Sales	$351.1	$247.9	$249.7	$356.8	$529.4
Cost of Goods	181.9	132.4	136.2	198.6	304.3
Oper. Income	169.1	115.5	113.4	158.2	225.1
Net Income (Loss)	26.7	(12.8)	(7.4)	27.9	48.6
Net Income as % of Sales	7.6%	(5.2%)	(3.0%)	7.8%	9.2%

Source: OIRA Industry Survey

Not surprisingly, the pattern in firm profitability closely tracks the industry's shipment trends, with years 1986 and 1987 showing net losses. Again, the years 1988 and especially 1989 demonstrate improvement in the position of the firms. It should be noted, however, that the individual respondents experienced a wide variety of situations. Two of the firms were consistently profitable throughout the period, while one firm consistently had negative net income; the other firms experienced market-driven swings.

From the limited survey data, there appears to be a correlation between profitability and company size. Of the three companies that had net sales of less than $20 million, only one showed a profit at any time between 1986 and 1989. In contrast, for the five companies with net sales in excess of $20 million, all showed positive profitability for at least two years during the period.

E. PRODUCTIVITY

One common measure of a firm's productivity is sales per employee. This figure was calculated for the nine companies responding to the OIRA survey. On average, sales per employee were $135,800 in 1989. The range was $65,000 to $193,000 for individual companies. There did not appear to be a correlation between productivity and size of company for the OIRA sample, nor any obvious differentiation in productivity by product group.

In a similar analysis, Dataquest calculated an average of $146,000 in sales per employee for 17 publicly-held wafer fabrication equipment manufacturers (front and back end). Dataquest's average for just front-end companies was $190,000, considerably higher than the OIRA sample. Furthermore, according to Dataquest, the average sales per employee for the broader electronics industry in 1989 was about $126,000. Thus, semiconductor equipment manufacturers' productivity was slightly higher than the average for the broader industry segment.

F. NATIONAL SECURITY ISSUES

Several questions on the BXA survey were designed to measure the vulnerabilities and capabilities of the semiconductor wafer processing equipment industry to support increased demand under national security emergency situations. National security considerations examined include expansion capabilities, bottlenecks to increased production, and reliance on foreign materials and parts.

1. Production Expansion Capabilities

The firms surveyed were asked to estimate how many months it would take to double their average monthly unit production rate under a national security emergency. They were to assume that the U.S. Government would underwrite financing for this expansion. The firms were also asked to describe the major constraints they foresaw to expansion. Responses were provided by production line.

On average, the firms indicated that it would take about 9 months to double their production rate. Responses ranged from a low of 3 months, for rapid thermal processing equipment, to 15 months for physical vapor deposition, epitaxial growth, and current ion implanters. The most common response was 12 months.

By far the most common production constraint named was a shortage of scientists, engineers, and skilled production workers, and the time to train them. Long lead times for parts, materials, and production/test equipment were also cited frequently. And, in three cases, respondents mentioned that plant facilities would need to be expanded to increase the production rate; this would require at least several months to accomplish.

2. Foreign Sourcing and Dependencies

All but two of the firms surveyed listed substantial reliance on foreign suppliers for necessary parts and components of wafer processing equipment. In total, the nine firms imported nearly $20 million of major parts and components for wafer processing equipment. This amounts to about 7 percent of their reported costs of goods sold. We believe that this figure is probably understated considerably, since some purchases that may appear to be from a domestic supplier or distributor may in fact be imported. For example, industry experts report that optical lenses are often supplied by Topel, a division of General Signal located in Rochester, New York. However, Topel sources most of its optical materials from abroad.

It was evident from the questionnaire that U.S. firms rely heavily on imported optical glass and/or lenses for use in lithography equipment. Firms indicated that there was no domestic supplier available or adequate to meet their needs in this regard; optical glass/lenses must be imported from sources in Germany and Japan, such as Hoya, Schott, and Carl Zeiss. This could have serious implications for the U.S. semiconductor manufacturing equipment industry, particularly the micro-lithography sector, in a crisis situation. As one firm put it, "The unavailability of [lenses or optical glass] would result in inability to ship systems -- manufacturing operations would cease; there is no second source [in the United States]."

In addition to optical supplies, another frequently mentioned foreign dependency was vacuum and turbo pumps, sourced from various countries including Japan, Germany, United Kingdom, and France. Again, the firms indicated that domestic sources for these pumps were not available, and that a sudden unavailability of these items would have a serious impact on the production of semiconductor wafer processing equipment.

A final area in which a pattern appeared in foreign sourcing was in the electronics sector. Companies cited reliance on foreign suppliers for integrated circuits, CRTs, electrical connectors, specialty electronics, resistors, disk drives, memory and I/O boards, and power supplies. While imported from multiple sources, Japan was by far the leading supplier in this area. In addition, single instances of foreign dependencies were reported for a wide variety of items, from ballscrews and bearings to connectors and controllers.

Evaluating overall foreign sourcing and dependency by country, Japan again appeared as the number one supplier (11 mentions). Germany was also named frequently (7 mentions), followed by the United Kingdom (4 mentions). Several countries registered two mentions each, including Canada, Korea, France and Italy, and a number of additional countries were named just once. In virtually every instance of foreign sourcing, the primary reason given was "domestic source not available or not adequate." Other frequently given reasons were lower cost and better quality.

Firms were also asked for recommendations to relieve foreign dependency in order to ensure a steady source of supply in a national emergency. The most frequent answer was to develop a second, domestic source for certain sole-sourced items, although some noted that this could be expensive and may not be supported by the market.

COMPETITIVENESS ISSUES

A. SURVEY RESULTS

The surveyed firms were asked about a wide range of competitiveness and technology issues. Their responses provide insight into the factors that affect the competitive position of the overall U.S. wafer processing equipment industry.

Eight out of the nine surveyed firms identified themselves as a "world leader" in at least one product field, including current ion implanters, 1X optical steppers, rapid processing and diffusion equipment, maskmaking equipment, focused ion beam systems, and 10X GaAs steppers. However, six out of the eight surveyed firms that said they were "world leaders" indicated that they were losing this lead. Five firms indicated that they were losing the lead to foreign firms (four Japanese and one European), and one firm indicated that it was losing the lead to another U.S. firm. One firm reported that it was maintaining its technological edge, but not expanding it further.

The firms were also asked to identify product segments in which they had lost a technology lead to a foreign firm during the past five years. Six of nine firms indicated that they had lost the technological lead in a particular product segment, three to Japanese firms and two to European firms. The particular product lines mentioned were 5X submicron i-line steppers (to Japan), focused ion-beam systems (to Japan), large exposure field for lithography (to Japan), high current ion implant (to Europe) and molecular beam epitaxy equipment (to Europe and Japan).

The firms also supplied information about specific instances in which they had lost sales to foreign competitors. The firms cited a broad array of reasons why sales were lost, including technology, reliability, performance, and delivery. However, by far the most common responses given were price and customer loyalty. The largest market for wafer fabrication equipment is Japan, and U.S. firms had difficulty in penetrating the Japanese market due to an alleged preference for Japanese equipment by Japanese chip makers.

Firms were asked to specify in which areas they believed they retained a competitive advantage over their major foreign competitors. Their responses are presented below.

There was consensus among U.S. firms that they had the advantage in terms of technology and innovation -- the "creative" aspects of wafer fabrication. There was also consensus that they were disadvantaged with regard to the cost of capital, overall business environment, and support from the Government, especially vis-à-vis Japanese companies.

SOURCES OF ADVANTAGE MENTIONED BY SURVEYED FIRMS

COMPETITIVE AREA	NUMBER OF FIRMS CITING COMPETITIVE ADVANTAGE
Overall Technology	6
Innovation	5
Delivery	4
Customer Satisfaction	4
Design Capability	3
Engineering Capability	3
Price	3
R&D Capability	2
Labor Availability	2
Product Quality	2
Government Assistance	1
Capital Costs	0
Business Environment	0

Source: OIRA Industry Survey

When asked about the impact on competitiveness of foreign competitors' plant size, several U.S. firms said that there is "absolutely no comparison" with foreign firms in terms of capacity. Many major foreign competitors are multimillion dollar, broad-based and vertically integrated companies. Because of their size, they have advantages in "purchasing, manufacturing, and most business areas." Size also allows foreign firms more latitude to support R&D and to carry larger inventories, even in slower economic times. Because of their size, they also have very close ties to their customer base through service offices and sales representatives located in the buying country. Nikon, Canon, and ASM were all named as having significant advantages in these areas. Nikon, with 1989 sales of $580 million, is estimated to spend between $50 and $75 million per year for research and development. On the other hand, U.S. firms characterized themselves as having limited economies of scale and lacking a large domestic customer base.

Seven of the nine surveyed firms believed that "unfair trade practices" gave their foreign competitors an advantage. Trade practices alleged as unfair included:

- Government Subsidies (Japan, France)
- Underpricing (Japan)
- Unfair Patent Royalties (Japan)
- Closed Markets (Japan, Europe)
- Use of "Demo" Machines (Japan)

Most of these comments were directed toward Japanese firms and the Japanese government; however, there were several references to European competitors, particularly with regard to government support and closed markets. One firm cited EC 1992 directives pertaining to the semiconductor industry as unfair.

Finally, several firms mentioned U.S. export control regulations as an unfair trade practice which has put them at a disadvantage vis-à-vis their overseas competitors. U.S. firms are not permitted to export certain equipment to certain regions for national security reasons, while Japanese and European firms are able to export, even when the equipment is supposedly subject to multilateral controls. Even in cases where export licenses are approved, the lengthy licensing process hinders U.S. competitiveness, according to the surveyed firms.[4]

The firms' self-appraisals for their future competitiveness were mixed. Three firms expected their situation to "decline greatly" or "decline slightly" due to their inability to maintain necessary levels of R&D spending to sustain a technological advantage. Three other firms expected their positions to "improve somewhat" in the next five years, although one indicated that this was dependent on "ability to fund future product development". They expressed confidence in the technological quality and design of their products. The remaining three firms

[4] U.S. export controls have been revised since the OIRA Industry Survey was conducted in response to changes in Eastern Europe. Pertinent changes that should alleviate the situation somewhat include decontrol of most equipment to the "China Green Line" and a new core list of controlled equipment on lithography and etch equipment capable of 2 micron and smaller line widths.

either would not make a prediction as to their future competitiveness, or believed that they would stay the same.

B. MAJOR FACTORS AFFECTING U.S. COMPETITIVENESS

There are numerous reasons for the decline of the U.S. wafer processing equipment industry. Discussion of broad economic factors such as access to low cost, patient capital, availability of well-educated workers, antitrust issues, and taxation that affect the overall business environment is beyond the scope of this study. These issues have been evaluated and recommendations proposed in a number of other analyses.[5]

This section addresses the factors which we believe to be major influences on U.S. competitiveness in this industry sector, which have received less attention. Many of these issues were also named by the firms surveyed in our study.

1. Loss of Consumer Electronics/Semiconductor Industry

The loss of the U.S. merchant semiconductor industry over the past ten years has been well documented. It is beyond the scope of this analysis to describe in detail the myriad factors that contributed to this decline. Chief among them was the migration of the semiconductor customer base, especially the consumer electronics industry, offshore. Other factors often cited include an adverse business environment (cost of capital, education, labor costs, etc.) in the United States compared to Japan, poor management and failure of U.S. semiconductor manufacturers to advance technology, and unfair trade practices.

Whatever the causes, the decline of the U.S. chip industry has been dramatic, as can be seen from the graph that follows. In Dynamic Random Access Memories (DRAMs), the largest semiconductor product category, the U.S. market share was 100 percent in 1976. By 1988, Japanese firms accounted for about 80 percent of the world market. This trend is replicated in other product segments to varying degrees. However, the loss of the DRAM market to Japanese competitors is one of the major factors affecting the U.S. wafer processing equipment industry. This is because DRAMs are one of the most important drivers for wafer processing equipment technologies. New equipment is often developed first

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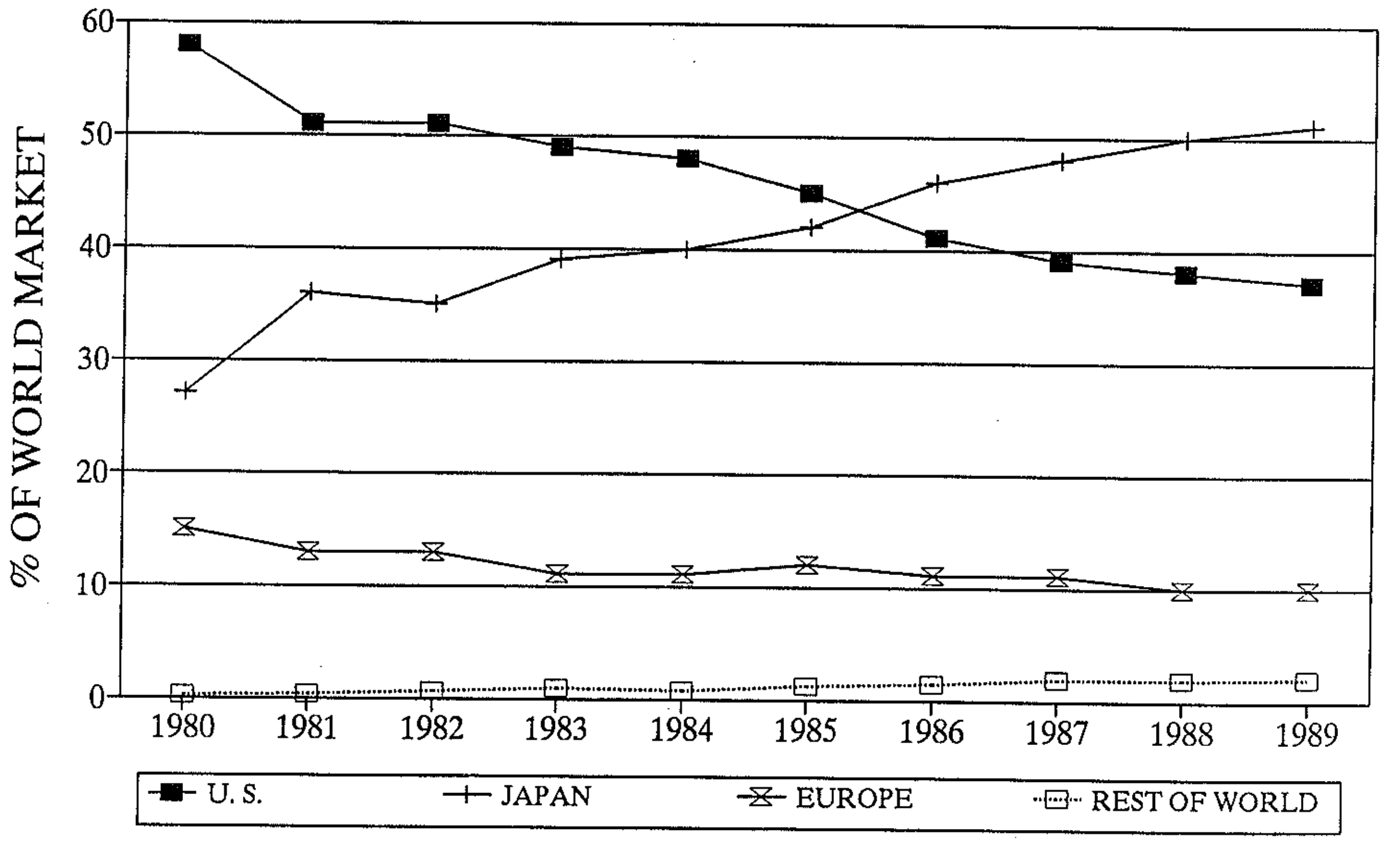
[5] See, for example, the reports and working papers of the National Advisory Committee on Semiconductors.

SHARE OF WORLD SEMICONDUCTOR MARKET
BY REGION OF ORIGIN OF SELLER



SOURCE: VLSI RESEARCH

for DRAM production because these devices are produced in large volumes and are relatively easy to test, allowing the performance of new wafer processing equipment to be readily evaluated.

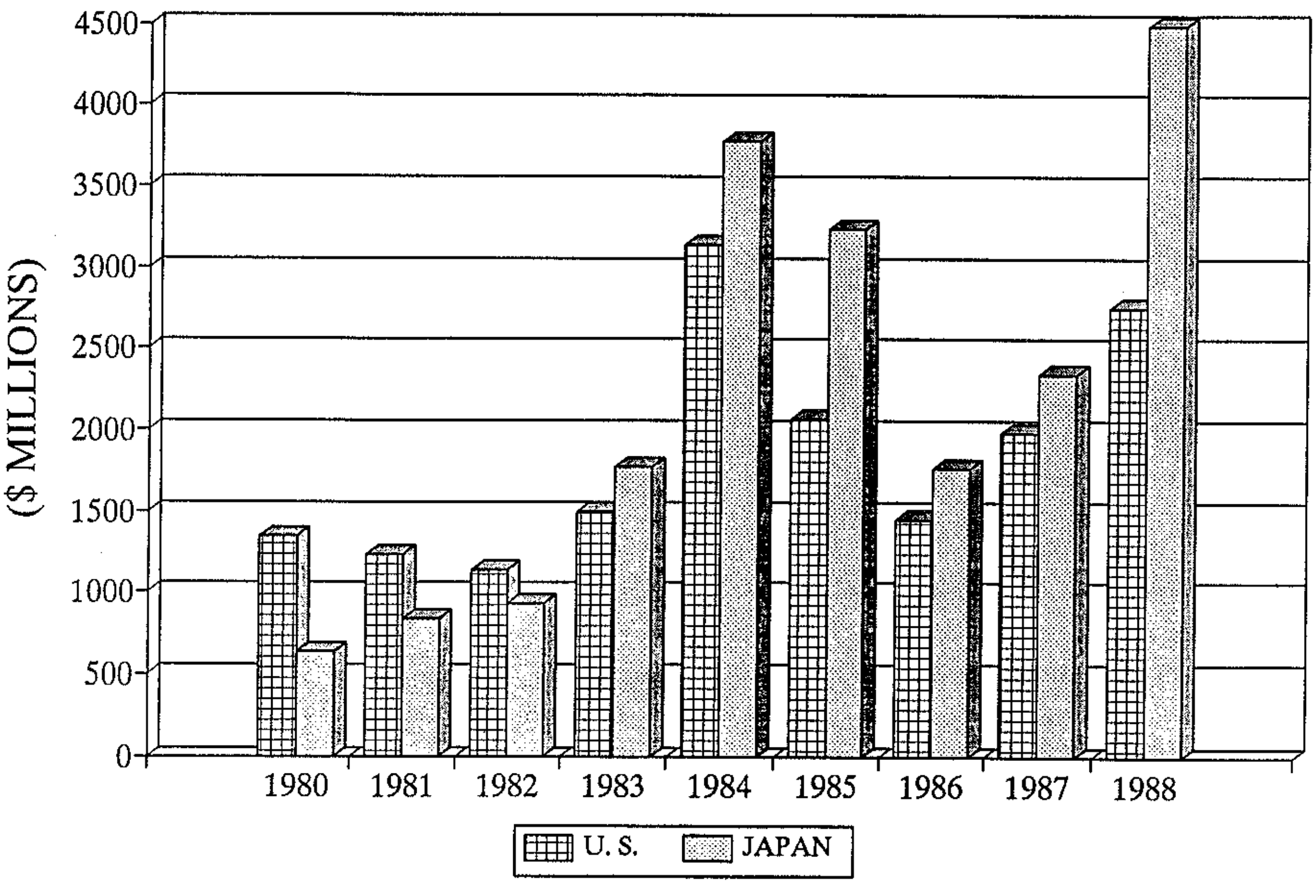
It is no surprise that the loss in U.S. share of world chip markets and in the U.S. chip manufacturing base was parallelled by a serious loss in market share for U.S. semiconductor equipment firms. Unlike most other capital goods industries which may serve many different sectors of the economy, the wafer processing equipment industry is restricted by definition to just one -- chip manufacturing.

Since the center of chip making has shifted outside the U.S., the market for wafer processing equipment is now largely outside of U.S. borders as well, especially in Japan. Japanese semiconductor manufacturers have outspent U.S. manufacturers on capital and equipment (including wafer processing equipment) every year since 1983 (see graph below). Exports are therefore extremely important to U.S. equipment manufacturers, but have been undermined because many major foreign chip producers prefer working with local sources of supply that they control.

Moreover, the transfer of semiconductor manufacturing to Japan led to rising competition from Japan in the equipment market itself. The growing Japanese share of world semiconductor production was the impetus for growth in the Japanese wafer processing equipment industry. In fact, Japan supplies nearly 80 percent of its own equipment for its massive semiconductor industry, up from 20 percent in the 1970s. This figure varies by type of equipment. Industry sectors in which Japanese firms are strongest, such as optical steppers, have especially low levels of imports, while other more specialized sectors, such as ion implanters and plasma chemical vapor deposition equipment, show higher levels of imports into Japan.

In order to gain access to world wafer processing equipment export markets, U.S. firms have increasingly established relationships with foreign firms, particularly in Japan (the largest single market). The firms surveyed by OIRA had a total of 15 relationships with foreign firms, ranging from sales

PLANT & EQUIPMENT EXPENDITURES
WORLD SEMICONDUCTOR MANUFACTURERS



NOTE: DATA EXCLUDES CAPTIVE PRODUCERS
SOURCE: DATAQUEST

representatives to wholly owned subsidiaries abroad. More than half of these relationships (9) were with Japanese firms, including one wholly owned subsidiary, four joint ventures engaged in manufacturing and sales, three distributor relationships engaged in sales and service only, and one licensee.

Interestingly, no other country besides Japan was named as manufacturing U.S. equipment under license or through a joint venture. This implies that in order to export to Japan, such an agreement is helpful. The remaining foreign relationships were for sales, service and distribution of U.S. equipment in Europe, Korea, and India. In one case, a U.S. firm serves as an importer of fully-made Japanese equipment (Tokyo Electron photoresist processors, plasma etch systems, and diffusion/oxidation furnaces) under a marketing agreement.

Establishing a relationship with a foreign firm, especially a manufacturing relationship, seems to involve some risk, however. In some cases, Japanese firms that were originally put into the wafer processing equipment business through a manufacturing relationship now compete with U.S. firms. An example is Anelva, which was established in 1967 as a joint venture between NEC of Japan and Varian Associates. Anelva now competes with Varian in the physical vapor deposition equipment market.

2. Industry Structure

As the surveyed firms pointed out, the relatively small average size of U.S. wafer processing equipment firms compared with their foreign competitors is a major disadvantage. According to Semiconductor Equipment and Materials International (SEMI), the industry's trade association, over 88 percent of U.S. semiconductor manufacturing equipment firms (including materials and test equipment suppliers) had sales of less than $25 million per year. Slightly more than six percent had sales between $25 and $100 million, and only five percent had sales in excess of $100 million per year. On average, major Japanese competitors are much larger. The major Japanese competitor in optical lithography, Nikon, has sales in excess of $580 million in its semiconductor production equipment operation alone. The relatively low sales volumes of U.S. firms prevent them from carrying large inventories, which leads to longer lead times for equipment. In contrast, Japanese lithography firms often maintain stocks of machines for immediate delivery.

Another area in which size of firm has a particular relevance is R&D spending. According to industry experts, the lifespan of wafer processing equipment is typically about five years. It costs an average of $50 million (and rising) to develop a new generation machine. If Japanese firms spend about the same percentage of sales on R&D (15-20 percent), a single Japanese firm such as Nikon may spend $75 million or more per year on R&D. As was demonstrated from the survey data, this exceeds the amount spent by nine major U.S. firms combined; the average annual R&D spending for the surveyed firms was $6 million. Thus, Japanese and even European firms are in a much better position to capitalize on R&D spending than U.S. firms, largely because their size and sales volumes allow them to do so.

In addition, major Japanese and European competitors are highly vertically integrated, further expanding their sales base and often providing a ready-made market for their products. For example, Hitachi, a major lithography equipment producer, is also one of Japan's biggest chip producers. Kokusai Electric which is active in ion implant, deposition, and etch equipment, is also part of the Hitachi industrial group (known as a kereitsu). Anelva is part of the NEC group, and Nikon and JEOL are part of the Mitsubishi kereitsu. Finally, Ulvac is a member of the Matsushita group of firms. It is important to note that Hitachi, NEC, Mitsubishi, and Matsushita are not only Japan's (and the world's) largest chip makers, but also produce a complete range of chip-consuming products, from TVs, stereos, and VCRs to aerospace avionics. These close inter-company relationships provide a means for Japanese wafer processing equipment producers to obtain additional funds for R&D, and to test prototype equipment in a production scenario. In Europe, ASM and ASM Lithography are owned by one of the largest European chip producers, Philips, so ASM also enjoys the benefits of vertical integration. In contrast, U.S. firms generally lack any ties to major U.S. merchant or captive chip producers such as Intel, Motorola, Texas Instruments and IBM.

In addition, U.S. firms have been hindered from undertaking joint research and development projects by U.S. antitrust laws. For example, Varian and Eaton have each invested millions of dollars in basic research for a new machine, duplicating one another's efforts. The two firms explored the idea of joint research, but were unable to cooperate without violating U.S. law. U.S. firms BTU and Thermco went one step further in sharing expenses on an R&D project, but were blocked by the Justice Department. However, when a Japanese competitor purchased Thermco, Justice approved the transaction. Antitrust considerations are typically reviewed only on a U.S. market basis, not on an international market basis.

The strong producer/supplier relationship in Japan makes it difficult for U.S. firms to penetrate the Japanese market or even to sell to Japanese transplants in the United States, while Japanese firms are relatively successful in selling to major U.S. chip makers. A recent study found that Japanese-owned facilities operating abroad were tightly controlled by the parent company to a much larger degree than American- and European-owned facilities outside their home countries. The higher degree of control was also found to limit the autonomy of Japanese subsidiaries in making purchasing and sourcing decisions. It found further that Japanese firms were much less likely to source using international competitive bidding procedures; rather, they go to a Japanese source.[6]

3. Government Support

Governments, including the United States, have historically attempted to foster the development of their semiconductor industries. This is perhaps due to the important role that developments in this industry play in national security and throughout the economy. Major government projects related to semiconductors are described below:

1) JAPAN:

One of the most important government-sponsored projects in the Japanese electronics sector was the Very Large Scale Integration (VLSI) project of 1976-1979. Organized by MITI, the VLSI project involved five of Japan's leading electronics systems firms (NEC, Hitachi, Fujitsu, Toshiba, and Mitsubishi). The government-funded and -sponsored R&D gave a tremendous boost to these firms in integrated circuit

[6] Mordechai E. Kreinin, "How Closed is Japan's Market? Additional Evidence."

manufacture, and helped establish a powerful wafer processing equipment base in Japan. Nikon, today the market leader in optical lithography, was brought into the business through the VLSI project because of its expertise in making lenses for cameras and other optical applications. Equally important, the project served to increase cooperation between the chip makers and their wafer processing equipment and materials suppliers. These producer/supplier relationships remain in place today.

The Japanese Government-owned Nippon Telephone and Telegraph Company (NTT) also played an important role in development of the Japanese microelectronics sector. Throughout the 1970s and 1980s, NTT worked closely with the major Japanese semiconductor firms to develop chips and production technologies for telecommunications and other applications. Today, there remain more than 50 consortia related to the electronics industry in Japan, according to Dataquest.

2) EUROPE:

One of the most important government-sponsored projects in Europe was the Megaproject, which ran from 1985 to 1989. This project teamed Siemens AG of West Germany & Philips NV of the Netherlands and their respective governments, which devoted more than $2 billion to develop processing technology to make state-of-the-art memory chips.

The Megaproject was succeeded recently by JESSI, the Joint European Submicron Silicon Project. This $4.5 billion program teams the three European Governments and the three largest European chip makers (Siemens, Philips, and Thomson of France), as well as European wafer processing equipment and materials suppliers. The objective of the 7-year project is to develop future generations of chips with circuit lines under 0.3 micron, and the equipment needed to produce them. IBM and SEMATECH are both being allowed to participate to a limited degree, and Japanese firms are also seeking participation.

Another multimillion dollar European government-sponsored cooperative R&D project is EUREKA (European Research Coordinating Agency). Twenty countries participate in EUREKA, which is designed to promote industrial cooperation within Europe in high technology fields. European governments fund about 40% of the EUREKA's budget. Many of the nearly 300 projects under EUREKA pertain to electronics; one is a U.K./Netherlands effort to develop a high-power excimer laser for semiconductor and other industrial uses.

ESPRIT (European Strategic Programme for Research and Development in Information Technology) is another government-funded project with relevance to semiconductor manufacturing. A key area of research for the 10 year project (started in 1984) is advanced microelectronics, with a goal to strengthen the European capabilities in Application Specific Integrated Circuits (ASICs).

3) UNITED STATES:

Although there are others, by far the largest example of U.S. Government support for the semiconductor industry was the Very High Speed Integrated Circuits (VHSIC) Program. Through this program, launched in 1979, the Department of Defense has spent nearly $1 billion to develop faster, more powerful ICs for use in weapons systems. Other smaller-scale programs were sponsored by the Department of Energy, NASA, and the National Science Foundation. Altogether, the Department of Defense accounts for over 75 percent of funding for these efforts, and other non-commercial agencies (DOE, NASA) account for most of the remainder.

Thus, while the U.S. has provided government support for semiconductor related industries as have Japan and Europe, there have been major differences in the nature of these support programs. U.S. programs have mainly pursued specific military objectives of the Department of Defense and have contributed little, at least directly, to commercial technology development. Japanese and European projects, on the other hand, have focused on commercial objectives, such as development of specific commercial products, equipment or processes.

In addition, Japanese and European government projects emphasized joint R&D and close cooperation among firms, while in U.S. projects this cooperation was not emphasized. Thus, overall, it appears that Japanese and European government support efforts have been effective in improving the commercial position of their semiconductor and wafer processing equipment manufacturers, while

U.S. projects have not. One possible exception to this pattern is SEMATECH.

SEMATECH

SEMATECH is a semiconductor research and development consortium based in Austin, Texas. It was founded in 1987 to boost the manufacturing technology of the U.S. semiconductor industry. Since then, 14 U.S.-owned, U.S.-based semiconductor firms (representing about 80 percent of the U.S. industry) have joined the consortium. In addition, U.S.-based semiconductor equipment and materials producers coordinate with SEMATECH through an independent organization known as SEMI/SEMATECH. The Federal Government (Department of Defense) funds approximately half of SEMATECH; the member companies fund the remainder. SEMATECH's current annual budget is about $200 million.

SEMATECH's establishment in 1987 followed several years of contraction by the U.S. semiconductor industry, particularly in the high-volume DRAM market, and acrimonious negotiations with Japan over semiconductor markets. The Department of Defense supported the founding of SEMATECH on national security grounds, acknowledging that manufacture of semiconductors contributes disproportionately to the national well-being through technological advancement, and has spillover effects throughout the economy.

SEMATECH was to have three phases, corresponding to integrated circuit designs with minimum feature size of 0.8 microns to start; 0.5 microns by 1992 (achieved in 1990); and 0.35 microns by 1993. A major focus of SEMATECH's research has become equipment improvement, in addition to production techniques. The consortium has signed outside R&D contracts with over 20 semiconductor manufacturing equipment producers (the first was signed in the spring of 1989), as well as with academic institutions and U.S. Government labs.

Thus, the difference between SEMATECH and previous U.S. Government efforts to foster the semiconductor industry is that SEMATECH has a manufacturing focus, unlike previous efforts, and is also less closely linked to specific military applications. Finally, SEMATECH seems to be nurturing cooperation between U.S. chip makers and their equipment suppliers. As yet, it is too soon to determine the effectiveness of SEMATECH and whether it will have a measurable effect on the competitiveness of U.S. equipment and device producers. It does appear to be a positive step.

4. Unfair Trade

Unfair trade practices have also adversely affected the U.S. wafer processing equipment industry. Foreign competitors of U.S. firms reportedly sell equipment at below-cost prices, or offer extremely favorable financing (no interest, long-term loans) to prospective purchasers in the U.S. and other markets. In addition, the nationality-based preferences for certain suppliers over others can be considered a type of unfair trade practice. As noted earlier, these practices were particularly favored by Japanese firms.

While the full implications of the economic unification of Europe by 1992 are not yet known, some in the semiconductor industry are concerned that EC 1992 directives are protectionist in nature. For example one directive changes the definition of "European-made" chips to only those that have been etched in Europe. As a result, U.S. and Japanese chip makers are establishing new facilities in Europe. This could provide export sales for U.S. equipment suppliers, unless the Europeans impose domestic content requirements in building these facilities.

Well-documented unfair trade practices in the semiconductor device sector have negatively affected the U.S. equipment industry. Dumping (selling below fair market value) in the U.S. market by Japanese chip manufacturers in the early- and mid-1980s was a major factor which led to the retrenchment of the U.S. semiconductor industry, particularly in the high-volume DRAM sector. This situation ultimately led to the 1986 Semiconductor Agreement with Japan, which was designed to put an end to dumping of Japanese DRAMs in the U.S., and to open the Japanese market to U.S. chip makers. Any damage done to the U.S. chip makers of course trickles down to their chain of suppliers, including the wafer processing equipment producers. Reportedly, the 1986 agreement has been of only limited usefulness to U.S. chip makers.

Finally, there is evidence that Japanese wafer processing equipment suppliers have withheld state-of-the-art equipment from U.S. chip producers, while they have provided them to Japanese makers. The U.S. General Accounting Office is currently investigating allegations of withheld technologies in this and other industry sectors. If true, this practice gives Japanese chip manufacturers an advantage over their American competitors, with negative repercussions for the U.S. chain of suppliers.

5. Foreign Investment

The past several years have seen numerous foreign acquisitions in the U.S. semiconductor industry. Many of these acquisitions were in the semiconductor manufacturing equipment and materials industries, as well as in the manufacturing of the devices themselves. This high level of foreign acquisition is additional evidence of the decline of U.S. control over semiconductor production and technologies. Even the acquisition of a minority stake in a U.S. semiconductor company can have an effect, through technology transfer and potential policy making power.

The table that follows lists some of the recent foreign investments by product category. Japan is by far the most active in acquisitions in this sector, but Germany, France, and Taiwan have also invested. In the wafer processing equipment industry there have been several acquisitions. One of the most significant was the 1989 acquisition of Materials Research Corporation (MRC) by Sony. MRC is a major force in the sputtering (deposition) sector, with over a fifth of the world market. The acquisition by Sony brings the Japanese share of the world market to more than 50 percent.

In addition, the sale of Varian's molecular beam epitaxy operation to France's Instruments S.A. (which owns Riber) was recently completed. This acquisition will give I.S.A/Riber a total of 47 percent of the market for this equipment, and will raise the total European market share to 66 percent. Varian also recently sold its cryopump operation to Ebara of Japan.

The small size of many U.S. wafer processing equipment producers, as well as their unique "niche" technologies, make them attractive to foreign investors. Potential U.S. purchasers, on the other hand, are often unwilling or unable to match the currency advantage of other countries relative to the dollar. One notable exception was the case of Perkin-Elmer. When Perkin-Elmer decided to sell its lithography and E-beam operations in

FOREIGN ACQUISITIONS IN THE U.S. SEMICONDUCTOR INDUSTRY

MATERIALS

U.S. COMPANY ACQUIRED	*ACQUIRING COMPANY/ COUNTRY OF ORIGIN*	*PRODUCT DESCRIPTION*
Monsanto Electric Materials Co.	Huels A.G. West Germany	Silicon Wafers
Cincinnati Milacron Semiconductor Materials Div.	Osaka Titanium Japan	Silicon Epitaxial Wafers
Union Carbide Chemicals and Plastics Co.	Komatsu Electronic Metals Japan	Polysilicon
Epitronics Corporation	Metallgesellschaft AG West Germany	Gallium Arsenide Epitaxial Wafers

SEMICONDUCTOR MANUFACTURE

U.S. COMPANY ACQUIRED	*ACQUIRING COMPANY/ COUNTRY OF ORIGIN*	*PRODUCT DESCRIPTION*
Silicon Systems, Inc.	TDK Japan	ASICs for Microcomputer Devices
Microwave Semiconductor Corporation	Thomson CSF France	Silicon Power Transistors
Integrated CMO Systems, Inc.	Toshiba/Mitsui Comtek Japan	ASICs
Advanced Micro Devices	Sony Corp. Japan	Complex Integrated Circuits
SEEQ Technology Inc.	Hualon Microelectronics Corp. Taiwan	EEPROMs
MOS Electronics Corp.	MOS Electronics Taiwan Taiwan	SRAMs
Synergy Semiconductor	Toshiba Corp. Japan	SRAMs
Sprague Electric Co. Semiconductor Group	Sanken Electric Co. Japan	Analog ICs and Semiconductors
National Semiconductor	Matsushita Corp. Japan	Diffusion of BiCMOS, SRAMs

SEMICONDUCTOR EQUIPMENT

U.S. COMPANY ACQUIRED	*ACQUIRING COMPANY/ COUNTRY OF ORIGIN*	*PRODUCT DESCRIPTION*
Micro Mask, Inc.	Hoya Corp. Japan	Photomasks
Materials Research Corp.	Sony Corp. Japan	Sputtering & Etching Equipment
Texas Instruments Inc. Photomask Operation	Toppan Printing Co. Japan	Photomasks
LTX Corp.	Sumitomo Metals, Inc. Japan	Testing Equipment
Semi-Gas Systems Div. of Hercules, Inc.	Nippon-Sanso Japan	Gas Purification Equipment
Lepton, Inc.	Canon Japan	E-Beam Systems
Quartz Division Verteq, Inc.	Heraeus Quarzglas GMBH West Germany	CVD Quartz Containers
Cryopump Operation of Varian Assoc.	Ebara Corp. Japan	Cryopumps for IC Manufacture
Molecular Beam Epitaxy Div. of Varian Assoc.	Instruments S.A. France	Molecular Beam Epitaxy Equipment

late 1989, several foreign firms, including Nikon and Canon, expressed interest. Industry experts believe that adverse public reaction to the potential loss of Perkin-Elmer to foreign interests, which had led the industry in optical lithography until the early 1980s, inhibited foreign acquisition. Instead, the lithography operation was purchased by the Silicon Valley Group, and the E-beam division was spun-off as ETEC, with financial and managerial backing from several large corporations, including IBM and Grumman, as well as SEMATECH. Unfortunately, while SEMATECH officials would like to see more industry cooperation as in the Perkin-Elmer case, they do not expect similar actions for other U.S. equipment producers.

Even foreign investment outside the wafer processing equipment sector can affect it. As U.S. semiconductor device producers are acquired by foreign firms, the domestic consumer base for production equipment may further erode. Even if semiconductor production is retained in this country after acquisition, studies have shown that foreign companies are likely to transfer their existing producer/supplier relationships to the acquired firm, implying that they are more likely to buy imported wafer processing equipment. This is especially true of Japanese-based companies, as discussed earlier.

6. Future Technology

Semiconductor producers are always seeking ways to cram more circuits onto chips to create faster, more powerful, and versatile products. Developing the equipment capable of making these increasingly powerful chips is technologically demanding and expensive. Thus, U.S. firms have had to devote an ever-increasing amount of their earnings to research and development programs in order to stay in this highly competitive business. U.S. wafer processing equipment firms spent an average of 5.9 percent of sales in 1979, compared to around 17 percent per year in recent years. Changes in technology occur quickly and a firm's survival in the fight for market share hinges on its ability to develop and adopt cutting edge technologies.

One primary area of technical constraints in the semiconductor industry is microlithography. Many experts believe that today's optical microlithography equipment has peaked in its ability to continue to push semiconductor technology. They believe that at levels below .25 microns, optical-based lithography systems will be inadequate due to decreases in depth of focus. For this reason, U.S., Japanese and European firms and/or governments are racing to develop more sophisticated, commercially-viable lithography equipment. X-ray lithography is the leading candidate among other forms of advanced lithography.

In x-ray lithography, a beam of x-rays substitutes for the light used in optical lithography. Because their wavelengths are much shorter than those of ultraviolet or visible light, x-rays can be used to imprint circuit features that are much narrower, allowing faster computer processing and greater information storage capabilities. There are three ways of generating x-rays: synchrotron, point source, and free electron lasers. Of these, the greatest amount of attention is being paid to synchrotron x-ray lithography systems, which use a large circular accelerator (a synchrotron) to produce x-rays from speeding atomic particles. One of the major challenges facing the industry is to make synchrotrons more economically-feasible through development of compact designs.

The U.S. Government funds some x-ray lithography research, mainly through the Department of Defense and the Department of Energy's National Labs. The funding for these efforts, however, is irregular and small-scale. The Congressional Budget Office estimates that, in aggregate, federal funding amounts to $60 million per year. In addition, private U.S. sources, primarily IBM, are active in x-ray lithography research.

Major federal efforts are as follows:

Louisiana State University -- Congress appropriated a total of $25 million in 1988 and 1989 to construct a conventional magnet synchrotron devoted to x-ray lithography. This is in the design phase, an estimated 2 years from completion.

Department of Energy -- DOE made a proposal in the spring of 1990 to jointly develop a "commercially-viable" synchrotron with U.S. industry. Costs will be equally shared up to $15 million in federal funds.

DARPA -- The Defense Advanced Research Projects Agency contracted with Brookhaven National Laboratory in 1988 to build a compact superconducting magnet synchrotron for x-ray lithography. The five-year contract is forecast at $31 million. In addition, DARPA funds work at the National Research Laboratory aimed at developing technologies to support x-ray lithography, such as maskmaking and materials.

SEMATECH also has a contract with Hampshire Instruments on x-ray lithography equipment. The Department of Defense has also supported Hampshire, a small U.S. firm that specializes in this technology.

In the private sector, IBM is estimated to have spent close to $500 million to construct a compact synchrotron in East Fishkill, Vermont. IBM contracted with Oxford Instruments of the U.K. to build this facility. In addition, IBM, Grumman, AT&T and others are involved in the Brookhaven research mentioned above.

Other governments, most notably Japan, are also actively pursuing R&D in x-ray lithography. The most well-known attempt is the MITI-sponsored SORTEC (Synchrotron Orbital Radiation Technology Consortium), a $70 million project to develop a compact synchrotron for x-ray lithography. SORTEC has multicompany participation. Nippon Telephone and Telegraph is also sponsoring a joint effort with Japanese semiconductor firms, and NTT recently announced that this effort has achieved greater x-ray output from a compact synchrotron than any other has previously achieved.

Europe's activities on x-ray lithography are less developed. However, the mission of Joint European Submicron Silicon Project (JESSI), as mentioned earlier, is to develop future generations of ICs with circuit lines under one micron, including equipment and materials to produce them efficiently. About 15 percent of JESSI's budget or $600 million is devoted to production processes, including development of optical, excimer laser, x-ray and electron beam lithography equipment.

The German government is also sponsoring joint research on x-ray lithography through the COSY consortium, which operates a compact synchrotron at the Fraunhofer Institute in Berlin. Finally, European governments and industry are collaborating through ESPRIT, which is chartered to develop supporting technologies, such as masks and resists, for x-ray lithography.

By all accounts, Japan currently leads the U.S. and Europe in the practical application of x-ray technology to microlithography. The U.S. is presently estimated to be at least two years behind in this effort. In all, Japan has in place seven synchrotrons dedicated to x-ray lithography, compared to two in the U.S. (IBM and Brookhaven).

FINDINGS

- The continued viability of the domestic semiconductor wafer processing equipment industry is critical to U.S. national security and economic competitiveness. This sector is considered by the Defense Department to be a key supporting industry for many of the most important future defense technologies, including superconductivity, passive sensors, and machine intelligence/robotics. Wafer processing equipment is the core technology for improvements in the performance of semiconductors and integrated circuits. Because of the broad use of these devices throughout the economy, the health of the wafer processing equipment sector is important for a wide range of industry sectors, computer-assisted manufacturing to aerospace.

- The U.S. share of the entire semiconductor manufacturing and equipment (SME) market, including machinery for both the front and back end processes, fell from 75 percent to 49 percent between 1980 and 1988. In the same period, Japanese market share rose from 18 percent to 39 percent. This shift parallelled the losses suffered by U.S. semiconductor and electronics manufacturers, the sole consumers of this equipment, at the hands of the Japanese industry.

- In certain sectors of the wafer processing equipment industry, the loss in market share was especially striking. Most dramatic was the shift in microlithography, and particularly in optical wafer steppers, where the U.S. share dropped from 60 percent to 15 percent in just five years; at the same time, Japan's portion of the world market almost doubled, from 39 percent to 75 percent. This shift is troublesome because optical microlithography is one of the key technologies driving improvements in semiconductor capabilities.

- While the U.S., European, and Japanese governments have all tried to foster the development of their semiconductor industries, there have been major differences in the nature of the support programs. U.S. programs have typically been focused on particular defense-related objectives and have done little to enhance the commercial strength of the industry. In contrast, foreign governments have directed their support toward non-military goals and have done much to enhance the commercial strength of their firms by nurturing strong producer/supplier relationships.

- One possible exception to the U.S. pattern of government support is SEMATECH. This industry-Government consortium, founded in 1987, seems to be fostering relationships between U.S. chip makers and their equipment suppliers. SEMATECH also has a more general manufacturing focus than previous U.S. Government efforts. However, the success or failure of SEMATECH is still to be determined.

- Semiconductor wafer processing equipment manufacturers surveyed cited anecdotal evidence of unfair trade practices, mentioning incidents of foreign competitors placing free "demo" machines in the factories of chip producers and selling their products at below market prices. At the same time, U.S. producers felt that they were unable to penetrate some markets abroad (especially in Japan), as well as hindered by U.S. export control policies.

- The mid-1980s were a time of retraction for the industry. The position of the industry declined in 1986 and 1987, when shipments, employment, and profitability all declined from previous levels. The next two years showed signs of recovery in all measures. However, while shipments and employment have increased, U.S. industry continues to lose ground to foreign competitors in market share.

- U.S. semiconductor wafer processing equipment producers would require nearly a year to double their production rates in a national security emergency. The biggest constraint to production increase is a shortage of skilled personnel, including production workers and scientists and engineers. Another significant national security concern is reliance on foreign parts and components, especially optics for use in lithography machines and various electronic devices used in all types of equipment.

- The small size of the average U.S. firm versus Japanese and European competitors is a major factor working against the competitive strength of U.S. wafer processing equipment producers.

- A related factor is the family-like structure of the foreign industry, particularly the Japanese "kereitsu." The largest of these families are fully vertically integrated, from the production of semiconductor manufacturing equipment to the manufacture of the chips themselves to the electronic end products. These strong producer-supplier relationships are difficult for outside firms to penetrate, and they also create a ready endmarket and sources of funding for Japanese wafer processing equipment producers.

- When compared to other domestic industries, U.S wafer processing equipment producers spent a high percentage of their sales revenues on research and development. While most R&D is funded in-house, 1988 and 1989 show sharp increases in "unconventional" forms of funding, especially R&D financed by the U.S. Government and by the equipment producers' customers. This could be an indication that the U.S. Government is reacting to the declining competitive situation of equipment producers, and a realization by chip producers that U.S. equipment manufacturers cannot afford to develop the next-generation systems alone.

- Despite this trend, the R&D spending of the U.S. industry paled in comparison with their Japanese counterparts' expenditures, primarily because of the Japanese firms' larger sales base and producer/supplier relationships. In addition, according to industry experts, U.S. antitrust laws hinder the ability of U.S. firms to undertake joint research and development projects.

- The result of lower U.S. R&D spending is that Japanese producers have led the way in some of the most advanced technologies. In some cases, U.S. chip producers claim that state-of-the-art equipment was withheld from them by Japanese suppliers. If this trend continues, the ability of U.S. industry to develop and commercialize future technologies such as x-ray lithography may be retarded. Failure to develop next-generation technologies will likely force more U.S. firms from this business and increase our reliance on foreign suppliers.

- Another factor contributing to the loss of U.S. leadership is high levels of foreign investment through acquisitions throughout the semiconductor supply chain. U.S. wafer processing equipment producers are particularly attractive to foreign investors because of their small size and command of niche technologies. Prospective U.S. buyers are often unable to match foreign bids due to adverse currency exchange rates and business conditions as well as antitrust concerns. Even minority acquisitions can lead to a loss of U.S. leadership through technology transfer.

RECOMMENDATIONS

Although many of the factors affecting the U.S. wafer processing equipment industry are determined by the overall business environment in the United States and overseas, there are some specific actions that can be taken by U.S. wafer processing equipment producers as well as the government toward the goal of maintaining and enhancing the competitiveness of this important industry:

1. **Wafer processing equipment producers are encouraged to develop mutually-beneficial strategic alliances with firms in Europe and Asia to enable them to enhance their access to markets and foreign R&D funding programs.**

2. **Our assessment has uncovered an apparent positive trend toward closer relationships between U.S. semiconductor equipment producers and chip manufacturers. U.S. industry is encouraged to expand and further develop these interrelationships, in both domestic and increasingly internationalized operations.**

3. **As part of its export promotion efforts, the U.S. government has strived to encourage exports of semiconductor manufacturing equipment. However, the U.S. government should increase its focus on factors which affect the ability of U.S. industry to sell overseas, including:**

    - Investigating reports of foreign competitors' unfair trade practices, and enforcing existing trade laws to ensure that U.S. firms are given adequate access to foreign markets.

    - Monitoring foreign customs, environmental, and other regulations to ensure that U.S. exports are not hindered.

    - Monitoring and disseminating information on EC 1992 Directives and their potential impact for U.S. wafer processing equipment producers (e.g., rules of origin).

4. **The U.S. government should improve data collection and reporting for the wafer processing equipment and other semiconductor manufacturing equipment industries.**

    Currently, shipment, employment, investment, and similar data are only available for the SME industry as part of a four-digit SIC code which includes other related and unrelated industries. It is nearly impossible to differentiate the performance of this industry from those of the others in the code. In addition, it is impossible to track export and import flows of wafer processing equipment due to its current classification under the Harmonized System.

- The wafer processing equipment industry should be treated as a unique industry sector in all U.S. data collection classifications, and data collected on this sector at the four-digit SIC level.

TAB A

SURVEY QUESTIONNAIRE

FORM BXA-0062

U.S. Department of Commerce
Bureau of Export Administration

OMB Approval Not Required: less than 10 respondents

NATIONAL SECURITY ASSESSMENT OF SEMICONDUCTOR WAFER PROCESSING EQUIPMENT MANUFACTURERS

THIS REPORT IS REQUIRED BY LAW

Failure to report can result in a maximum fine of $1,000 or imprisonment up to one year, or both. Information furnished herewith is deemed confidential and will not be published or disclosed except in accordance with Section 705 of the Defense Production Act of 1950, as amended (50 U.S.C. App. Sec. 2155).

GENERAL INSTRUCTIONS

1. Please complete this questionnaire in its entirety as it applies to U.S. semiconductor wafer processing equipment manufacturing and related operations. **Your response is due by February 23, 1990.** The survey has seven parts as follows:

   Part I: FIRM IDENTIFICATION
   Part II: PRODUCTION CAPABILITIES AND FOREIGN DEPENDENCE
   Part III: SHIPMENTS AND EXPORTS
   Part IV: TECHNOLOGY
   Part V: APPLICATIONS AND MARKETS
   Part VI: FINANCIAL INFORMATION
   Part VII: COMPETITIVENESS

2. Complete Part II separately for each of your establishments that produce semiconductor wafer processing equipment in the United States. Please make photocopies of this section if additional pages are needed.

3. For Parts I, III, IV, V, VI and VII, firms operating more than one establishment may combine the data for all establishments into a single report. Any necessary comments or explanations should be supplied in the space provided or on separate sheets attached to this questionnaire. Ensure that you reference the proper question if you use extra sheets. If any answer is "none", please indicate.

4. It is not our desire to impose an unreasonable burden on any respondent. IF INFORMATION IS NOT READILY AVAILABLE FROM YOUR RECORDS IN EXACTLY THE FORM REQUESTED, FURNISH ESTIMATES AND DESIGNATE BY THE LETTER "E".

5. Information furnished in response to this questionnaire will be treated as proprietary and will not be published or divulged to reveal the operations of individual firms.

6. Questions related to the questionnaire should be directed to Mr. Brian Nilsson, Trade and Industry Analyst, at (202) 377-2322, or Mr. John Tucker, Senior Industry Analyst, at (202) Department of Commerce.

7. Before returning your completed questionnaire, be sure to sign the certification and identify the person and a phone number should we need to contact your firm. Return completed questionnaire to:

Mr. Brad Botwin, Director
Strategic Analysis Division, Rm. 3878
Office of Industrial Resource Admin.
U.S. Department of Commerce
Washington, D.C. 20230

DEFINITIONS

ESTABLISHMENT - All facilities in which semiconductor wafer processing equipment is produced. Includes auxiliary facilities operated in conjunction with (whether or not physically separate from) such production facilities. Does not include wholly-owned distribution facilities.

FIRM - An individual proprietorship, partnership, joint venture, association, corporation (including any subsidiary corporation in which more than 50 percent of the outstanding voting stock is owned), business trust, cooperative, trustees in bankruptcy, or receivers under decree of any court, owning or controlling one or more establishments as defined above.

PRACTICAL CAPACITY - (For purposes of determining capacity utilization in question #1 of Part II, please consider the following.) Sometimes referred to as engineering or design capacity, this is the greatest level of output a semiconductor wafer processing equipment manufacturing establishment can achieve within the framework of a realistic work pattern. In estimating practical capacity, take into account the following considerations:

1. Under most circumstances assume your 1989 product mix. If no production took place in 1989 of a particular item or items which you have, or will have the capability to produce and can anticipate receiving orders for in the future, include a reasonable quantity as part of your 1989 product mix.

2. Consider only the machinery and equipment in place and ready to operate. Do not consider facilities which have been inoperative for a long period of time and, therefore, require extensive reconditioning before they can be made operative.

3. Take into account the additional downtime for maintenance, repair, or clean-up which would be required as you move from current operations to full capacity.

4. Do not consider overtime pay, added costs for materials, or other costs to be limiting factors in setting capacity.

5. Although it may be possible to expand plant output by using productive facilities outside of the plant, such as by contracting out subassembly work, do not assume the use of such outside facilities in greater proportion than has been characteristic of your operations.

PRODUCTION WORKERS - Persons, up through the line supervisor level, engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, or shipping. In addition, persons engaged in supporting activities such as maintenance, repair, product development, auxiliary production for your firm's own use, record keeping, and other services closely associated with production operations at your firm. Employees above the working supervisor level are excluded from this item.

RESEARCH AND DEVELOPMENT - Research and development includes basic and applied research in the sciences and in engineering, and design and development of prototype products and processes. For the purposes of this questionnaire, research and development includes activities carried on by persons trained, either formally or by experience, in the physical sciences including related engineering, if the purpose of such activity is to do one or more of the following things:

1. Pursue a planned search for new knowledge, whether or not the search has reference to a specific application.

2. Apply existing knowledge to problems involved in the creation of a new product or process, including work required to evaluate possible uses.

3. Apply existing knowledge to problems involved in the improvement of a present product or process.

SCIENTISTS AND ENGINEERS - Persons engaged in research and development work or production operations that have at least a four-year college education in the physical sciences or engineering.

SHIPMENTS - Report unit and dollar values of domestically produced semiconductor wafer processing equipment shipped by your firm from 1985-1989 for each equipment category listed for questions in Part III. Such shipments should include inter-plant or intra-plant transfers, but should exclude shipments of products produced by other manufacturers for resale under your brand name. Do not adjust for returned shipments.

UNITED STATES - The term "United States" includes the fifty States, Puerto Rico, the District of Columbia, and the Virgin Islands.

PART I. FIRM IDENTIFICATION

1. COMPANY ADDRESS: Please provide the name and address of your firm or corporate division.

____

____

____

2. PARENT FIRM: If your firm is wholly or partly owned by another firm, indicate the name and address of the parent firm and extent of ownership.

____

____

____

Ownership: _________ %

3. BUY/SELL SOLICITATIONS: If your firm has received inquiries or solicitations from another firm about purchasing or merging semiconductor wafer processing equipment operations; or, if you have offered or solicited bids to sell these operations in the last year, please describe below the circumstances, naming the firm(s) involved, the parts of your assets in the consideration, the purchase/selling price offered, and the reason the solicitation took place.

____

____

____

4. R & D FACILITY: If you have a separate facility(ies) or building dedicated to semiconductor manufacturing equipment research and development, please provide the facility's address and current number of full time employees below.

Address: ______________________ Full Time Employment: _________

____

____

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FIRM IDENTIFICATION (continued)

5. U.S. MANUFACTURING ESTABLISHMENT LOCATIONS: Identify the location of your semiconductor wafer processing equipment establishment(s) in the United States, and from the coded list that follows, the types of wafer processing machines produced at each facility. (See definition of establishment)

Wafer Processing Equipment
(letter codes)

Aligners: a) Contact/Proximity, b) Scan Optical, c) Step and Repeat, d) X-Ray, e) Other (describe)

Other Lithography Systems: f) E-Beam Direct Writers, g) E-Beam Mask Makers, h) Focused Ion Beam Writers, i) Laser Mask Makers, j) Mask Repair Systems

Thin and Thick Film Deposition: k) Chemical Vapor, l) Physical Vapor, m) Epitaxial Growth, n) Sputtering

Etch and Strip: o) Wet Etch, p) Plasma Etch, q) Reactive Ion Etch, r) Stripping Systems

Ion Implantation: s) Current Ion Implanters, t) High Voltage Ion Implanters

Metrology: u) Wafer Metrology, v) Mask Metrology

Thermal Processes: w) Diffusion/Oxidation Furnaces, x) Rapid Thermal Processing

Other Wafer Processing Equipment and Parts: y) Other, including masks (describe), z) Parts (for any of the above)

Locality	State	Zip Code	Type Wafer Processing Equipment Manufactured (please use letter codes)

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FIRM IDENTIFICATION (continued)

6. DOMESTIC AND FOREIGN RELATIONSHIPS: In the space provided below, please list the joint ventures, partnerships, teaming efforts, licenses, marketing agreements, or other arrangements you have associated with your wafer processing equipment operations with domestic and foreign firms.

Domestic:

Type Relationship	U.S. Partner's Name	Primary Activity

Foreign:

Type Relationship	Foreign Partner's Name	Country	Primary Activity

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PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE

1. PRODUCTION AND CAPACITY UTILIZATION. (Complete Part II for each U.S. establishment.) Enter total 1989 production of semiconductor wafer processing equipment in units produced and market value, and your capacity utilization rate (See definition of PRACTICAL CAPACITY.)

Establishment:________________

	1989 Unit Production	1989 Production Value ($000)	1989 Capacity Utilization
ALIGNERS			
(1) Contact/proximity	______	______	______
(2) Scan Optical	______	______	______
(3) Step and Repeat	______	______	______
(4) X-Ray	______	______	______
(5) Other (Describe) (________)	______	______	______
OTHER LITHOGRAPHY SYSTEMS			
(1) E-Beam Direct Writers	______	______	______
(2) E-Beam Mask Makers	______	______	______
(3) Focused Ion Beam Writers	______	______	______
(4) Laser Mask Makers	______	______	______
(5) Mask Repair Systems	______	______	______
THIN AND THICK FILM DEPOSITION			
(1) Chemical Vapor Deposition	______	______	______
(2) Physical Vapor Deposition	______	______	______
(3) Epitaxial Growth	______	______	______
(4) Sputtering	______	______	______
ETCH AND STRIP			
(1) Wet Etch	______	______	______
(2) Plasma Etch	______	______	______
(3) Reactive Ion Etch	______	______	______
(4) Stripping Systems	______	______	______
ION IMPLANTATION			
(1) Current Ion Implanters	______	______	______
(2) High Voltage Ion Implanters	______	______	______

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PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)

1. PRODUCTION AND CAPACITY UTILIZATION. (Complete Part II for each U.S. establishment.) Enter total 1989 production of semiconductor wafer processing equipment in units produced and market value, and your capacity utilization rate (See definition of PRACTICAL CAPACITY.)

Establishment: ______________

	1989 Unit Production	1989 Production Value ($000)	1989 Capacity Utilization
METROLOGY EQUIPMENT			
(1) Wafer Metrology	______	______	______
(2) Mask Metrology	______	______	______
THERMAL PROCESSES			
(1) Diffusion/Oxidation Furnaces	______	______	______
(2) Rapid Thermal Processing	______	______	______
OTHER EQUIPMENT AND PARTS			
(1) Other Wafer Processing Equipment (including Masks)	______	______	______
(2) Parts (for any of the above)	NA	______	______

PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

2. PRODUCTION EXPANSION CAPABILITIES: Under a national security emergency with financing underwritten by the Federal Government, how many months would it take to double the average monthly unit production rate you experienced in 1989 (i.e., 1989 unit production divided by 12); and what constraints (e.g., skilled labor, lead time for additional production equipment, supplies, etc.) would limit your expansion capability?

	Expansion Time and Constraints Months	Constraints
Aligners		
(1) Contact/Proximity	______	______
(2) Scan Optical	______	______
(3) Step and Repeat	______	______
(4) X-Ray	______	______
(5) Other (describe)	______	______
Other Lithography Systems		
(1) E-Beam Direct Writers	______	______
(2) E-Beam Mask Makers	______	______
(3) Focused Ion Beam Writers	______	______
(4) Laser Mask Makers	______	______
(5) Mask Repair Systems	______	______
Thin and Thick Film Deposition		
(1) Chemical Vapor	______	______
(2) Physical Vapor	______	______
(3) Epitaxial Growth	______	______
(4) Sputtering	______	______
Etch and Strip		
(1) Wet Etch	______	______
(2) Plasma Etch	______	______
(3) Reactive Ion Etch	______	______
(4) Stripping Systems	______	______
Ion Implantation		
(1) Current Ion Implanters	______	______
(2) High Voltage Ion Implanters	______	______
Metrology/Thermal Processes		
(1) Wafer Metrology	______	______
(2) Mask Metrology	______	______
(3) Diffusion/Oxidation Furnaces	______	______
(4) Rapid Thermal Processing	______	______
Other Wafer Processing Equipment and Parts		
(1) Other Wafer Processing Equipment (including masks)	______	______
(2) Parts (for any of the above)	______	______

PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

3. IMPORTED PARTS AND COMPONENTS: Complete the following table addressing which foreign made parts and components (i.e., lenses, circuit boards, NC or CNC controls, electric motors, etc.) you use in the production or assembly of semiconductor wafer processing equipment. Use the following coded reasons why a foreign source is used in completing the table.

A. Domestic source not available or inadequate
B. Lower cost
C. Quicker delivery
D. Better quality
E. Other (specify)

Item Name	1989 Imported Value	Foreign Supplier Firm	Country of Origin	Reason Foreign Sourced (use codes)
____	$____	____	____	____
____	$____	____	____	____
____	$____	____	____	____
____	$____	____	____	____
____	$____	____	____	____
____	$____	____	____	____

4. FOREIGN DEPENDENCE: For any foreign sourced items designated by "A" above (i.e., domestic source not available or inadequate), please describe: a) the adverse impact an interruption in the item's availability would have on your manufacturing operations, b) what measures can be taken to minimize any adverse impacts and, c) the reason(s) the parc or component is not produced in the United States (i.e., lack competitiveness, behind in technology, foreign marketing practices, etc.).

____

____

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____

PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

5. IMPORTS OF WAFER PROCESSING MACHINERY: Please complete the following table addressing what semiconductor wafer processing equipment you imported in 1989, and the reasons for importing. Use the following coded reasons why a foreign source is used in completing the table.

A. Rationalization of global operations
B. Round out product offerings
C. Building market share to enter this line
D. Maintain market share against others
E. Import is technically ahead of my offerings
F. Marketing agreement
G. Other (describe)

Equipment Type	1989 Value Imported	Foreign Producer Firm	Reason Foreign Sourced (use codes)
____________	$________	____________	____________
____________	$________	____________	____________
____________	$________	____________	____________
____________	$________	____________	____________

6. EMPLOYMENT: Enter the number of employees (end of year) at this establishment from 1985-1989, as requested below. (See definitions of Scientists and Engineers, and of Production Workers)

	1985	1986	1987	1988	1989
Scientists and Engineers	______	______	______	______	______
Production Workers	______	______	______	______	______
Admin. and Others	______	______	______	______	______
Totals	______	______	______	______	______

7. LABOR CONCERNS: If in the last five years you experienced any labor concerns, such as shortages of certain skills, excessive turnover, union activities, etc. that adversely affect(ed) your manufacturing operations, please describe them below.

____

____

1. SHIPMENTS (in units shipped). Enter total annual shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989

	(in units shipped)				
	1985	1986	1987	1988	1989
ALIGNERS					
(1) Contact/proximity	______	______	______	______	______
(2) Scan Optical	______	______	______	______	______
(3) Step and Repeat	______	______	______	______	______
(4) X-Ray	______	______	______	______	______
(5) Other (Describe) (______________)	______	______	______	______	______
OTHER LITHOGRAPHY SYSTEMS					
(1) E-Beam Direct Writers	______	______	______	______	______
(2) E-Beam Mask Makers	______	______	______	______	______
(3) Focused Ion Beam Writers	______	______	______	______	______
(4) Laser Mask Makers	______	______	______	______	______
(5) Mask Repair Systems	______	______	______	______	______
THIN AND THICK FILM DEPOSITION					
(1) Chemical Vapor Deposition	______	______	______	______	______
(2) Physical Vapor Deposition	______	______	______	______	______
(3) Epitaxial Growth	______	______	______	______	______
(4) Sputtering	______	______	______	______	______
ETCH AND STRIP					
(1) Wet Etch	______	______	______	______	______
(2) Plasma Etch	______	______	______	______	______
(3) Reactive Ion Etch	______	______	______	______	______
(4) Stripping Systems	______	______	______	______	______
ION IMPLANTATION					
(1) Current Ion Implanters	______	______	______	______	______
(2) High Voltage Ion Implanters	______	______	______	______	______

2. SHIPMENTS (in units shipped). Enter total annual shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in units shipped) 1985	1986	1987	1988	1989
METROLOGY EQUIPMENT					
(1) Wafer Metrology	______	______	______	______	______
(2) Mask Metrology	______	______	______	______	______
THERMAL PROCESSES					
(1) Diffusion/Oxidation Furnaces	______	______	______	______	______
(2) Rapid Thermal Processing	______	______	______	______	______
OTHER EQUIPMENT AND PARTS					
(1) Other Wafer Processing Equipment (including Masks)	______	______	______	______	______
(2) Parts (for any of the above)	NA	NA	NA	NA	NA

2. SHIPMENTS (in dollars). Enter total annual shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in thousands of dollars)				
	1985	1986	1987	1988	1989
ALIGNERS					
(1) Contact/proximity					
(2) Scan Optical					
(3) Step and Repeat					
(4) X-Ray					
(5) Other (Describe)					
(__________)					
OTHER LITHOGRAPHY SYSTEMS					
(1) E-Beam Direct Writers					
(2) E-Beam Mask Makers					
(3) Focused Ion Beam Writers					
(4) Laser Mask Makers					
(5) Mask Repair Systems					
THIN AND THICK FILM DEPOSITION					
(1) Chemical Vapor Deposition					
(2) Physical Vapor Deposition					
(3) Epitaxial Growth					
(4) Sputtering					
ETCH AND STRIP					
(1) Wet Etch					
(2) Plasma Etch					
(3) Reactive Ion Etch					
(4) Stripping Systems					
ION IMPLANTATION					
(1) Current Ion Implanters					
(2) High Voltage Ion Implanters					

SHIPMENTS AND EXPORTS (continued)

2. SHIPMENTS (in dollars). Enter total annual shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in thousands of dollars)				
	1985	1986	1987	1988	1989
METROLOGY EQUIPMENT					
(1) Wafer Metrology	________	________	________	________	________
(2) Mask Metrology	________	________	________	________	________
THERMAL PROCESSES					
(1) Diffusion/Oxidation Furnaces	________	________	________	________	________
(2) Rapid Thermal Processing	________	________	________	________	________
OTHER EQUIPMENT AND PARTS					
(1) Other Wafer Processing Equipment (including Masks)	________	________	________	________	________
(2) Parts (for any of the above)	________	________	________	________	________

2. EXPORT SHIPMENTS (in units shipped for export). Enter total annual export shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	1985	1986	1987	1988	1989
	(in units shipped for export)				
ALIGNERS					
(1) Contact/proximity	____	____	____	____	____
(2) Scan Optical	____	____	____	____	____
(3) Step and Repeat	____	____	____	____	____
(4) X-Ray	____	____	____	____	____
(5) Other (Describe) (________)	____	____	____	____	____
OTHER LITHOGRAPHY SYSTEMS					
(1) E-Beam Direct Writers	____	____	____	____	____
(2) E-Beam Mask Makers	____	____	____	____	____
(3) Focused Ion Beam Writers	____	____	____	____	____
(4) Laser Mask Makers	____	____	____	____	____
(5) Mask Repair Systems	____	____	____	____	____
THIN AND THICK FILM DEPOSITION					
(1) Chemical Vapor Deposition	____	____	____	____	____
(2) Physical Vapor Deposition	____	____	____	____	____
(3) Epitaxial Growth	____	____	____	____	____
(4) Sputtering	____	____	____	____	____
ETCH AND STRIP					
(1) Wet Etch	____	____	____	____	____
(2) Plasma Etch	____	____	____	____	____
(3) Reactive Ion Etch	____	____	____	____	____
(4) Stripping Systems	____	____	____	____	____
ION IMPLANTATION					
(1) Current Ion Implanters	____	____	____	____	____
(2) High Voltage Ion Implanters	____	____	____	____	____

2. EXPORT SHIPMENTS (in units shipped for export). Enter total annual export shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in units shipped for export)				
	1985	1986	1987	1988	1989
METROLOGY EQUIPMENT					
(1) Wafer Metrology	______	______	______	______	______
(2) Mask Metrology	______	______	______	______	______
THERMAL PROCESSES					
(1) Diffusion/Oxidation Furnaces	______	______	______	______	______
(2) Rapid Thermal Processing	______	______	______	______	______
OTHER EQUIPMENT AND PARTS					
(1) Other Wafer Processing Equipment (including Masks)	______	______	______	______	______
(2) Parts (for any of the above)	NA	NA	NA	NA	NA

4. EXPORT SHIPMENTS (in dollars). Enter total annual export shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in thousands of dollars) 1985	1986	1987	1988	1989
ALIGNERS					
(1) Contact/proximity					
(2) Scan Optical					
(3) Step and Repeat					
(4) X-Ray					
(5) Other (Describe) (____________)					
OTHER LITHOGRAPHY SYSTEMS					
(1) E-Beam Direct Writers					
(2) E-Beam Mask Makers					
(3) Focused Ion Beam Writers					
(4) Laser Mask Makers					
(5) Mask Repair Systems					
THIN AND THICK FILM DEPOSITION					
(1) Chemical Vapor Deposition					
(2) Physical Vapor Deposition					
(3) Epitaxial Growth					
(4) Sputtering					
ETCH AND STRIP					
(1) Wet Etch					
(2) Plasma Etch					
(3) Reactive Ion Etch					
(4) Stripping Systems					
ION IMPLANTATION					
(1) Current Ion Implanters					
(2) High Voltage Ion Implanters					

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SHIPMENTS AND EXPORTS (continued)

2. EXPORT SHIPMENTS (in dollars). Enter total annual export shipments of semiconductor wafer processing equipment of the types listed below for 1985-1989.

	(in thousands of dollars)				
	1985	1986	1987	1988	1989
METROLOGY EQUIPMENT					
(1) Wafer Metrology	____	____	____	____	____
(2) Mask Metrology	____	____	____	____	____
THERMAL PROCESSES					
(1) Diffusion/Oxidation Furnaces	____	____	____	____	____
(2) Rapid Thermal Processing	____	____	____	____	____
OTHER EQUIPMENT AND PARTS					
(1) Other Wafer Processing Equipment (including Masks)	____	____	____	____	____
(2) Parts (for any of the above)	____	____	____	____	____

PART IV. TECHNOLOGY

1. RESEARCH AND DEVELOPMENT: Please enter research and development expenditures from 1985-1989, associated with your semiconductor wafer processing equipment operations as requested below. Enter separately the dollar amounts (in $000s) financed by your firm (in-house), the government, a customer, or as part of a joint venture. (See definition of Research and Development)

Source of Funding	1985	1986	1987	1988	1989
	(in thousands of dollars)				
In-house	______	______	______	______	______
Government	______	______	______	______	______
Customer	______	______	______	______	______
Joint Venture	______	______	______	______	______
Other (specify) (________________)	______	______	______	______	______
Totals	______	______	______	______	______

2. AREAS OF R & D EFFORT: For 1989, please enter research and development expenditures (in $000s) in the areas specified below.

Area		Expenditures
Electron Beam		$____________
E-Beam Direct	$__________	
E-Beam Mask Maker	$__________	
Ion Beam		$____________
Optical Lithography*		$____________
Laser Mask Maker		$____________
X-Ray		$____________
Other (specify) (________________)		$____________

*(includes excimer laser lithography)

TECHNOLOGY (continued)

3. TECHNOLOGY RANKING: Please specify those manufacturing processes, product offerings, in-house know-how, or other technologies associated with your semiconductor manufacturing equipment operations, where your firm is A) the world leader, and B) the U.S. leader. Also, please identify your nearest competitor (either domestic or foreign) in the area you lead, and whether your lead in the area has increased(+)/decreased(-) in the last three years.

A) World Leader in:

i) Manufacturing Process(es): (describe) ______________________

____

Nearest Competitor: ____________ / ____________ / ____________
(name) (country) (lead=+-)

ii) Product Offering(s): (specify) ______________________

____

Nearest Competitor: ____________ / ____________ / ____________
(name) (country) (lead=+-)

iii) In-House Know-how: (specify) ______________________

____

Nearest Competitor: ____________ / ____________ / ____________
(name) (country) (lead=+-)

iv) Other Technology(ies): (specify) ______________________

____

Nearest Competitor: ____________ / ____________ / ____________
(name) (country) (lead=+-)

TECHNOLOGY (continued)

question #3 - TECHNOLOGY RANKING (continued)

B) United States Leader in:

i) Manufacturing Process(es): (describe) ____________________

____

Nearest Competitor: ______________ / ______________ / ______________
(name) (country) (lead=+-)

ii) Product Offering(s): (specify) ____________________

____

Nearest Competitor: ______________ / ______________ / ______________
(name) (country) (lead=+-)

iii) In-House Know-how: (specify) ____________________

____

Nearest Competitor: ______________ / ______________ / ______________
(name) (country) (lead=+-)

iv) Other Technology(ies): (specify) ____________________

____

Nearest Competitor: ______________ / ______________ / ______________
(name) (country) (lead=+-)

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TECHNOLOGY (continued)

4. TECHNOLOGY LEAD LOST: Please indicate for the semiconductor wafer processing equipment areas listed below where your firm has lost the technology lead to a foreign firm during the past five years; and provide the name of the foreign firm that has the lead in the area today.

i) Manufacturing Process(es): (describe) ______________________

____

Foreign Technology Leader: ______________ / ______________
(name) (country)

ii) Product Offering(s): (specify) ______________________

____

Foreign Technology Leader: ______________ / ______________
(name) (country)

iii) In-House Know-how: (specify) ______________________

____

Foreign Technology Leader: ______________ / ______________
(name) (country)

iv) Other Technology(ies): (specify) ______________________

____

Foreign Technology Leader: ______________ / ______________
(name) (country)

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PART V. APPLICATIONS AND MARKETS

1A. APPLICATIONS: Please complete the following table, identifying your largest sale in 1989 of semiconductor wafer processing equipment for producing semiconductors for use in each of the following markets: A) Military, B) Industrial, C) Commercial (i.e., consumer electronics), and D) Space Applications. For each market, provide the name of the customer, the type of wafer processing equipment (you may use the letter codes describing the equipment on page 2 of this questionnaire), the units and dollar value sold, and the intended purpose to which the equipment will be put. (Please enter "none" if you made no sales into a particular market.)

Intended Purpose of Semiconductor Wafer Processing Equipment
(select one or more)

To produce semiconductors:
a) in high volume
b) for special applications with lower volume requirements
c) for use in special environments (i.e., radiation, thermal, vacuum applications, etc.)
d) made with special compounds (i.e., gallium arsenide, indium phosphide, etc.
e) other (specify:________________________)

A) Military:

Customer Name	Type Equipment	# of Units	Dollar Value	Purpose (Use Codes)
______________	________________	_____	$______	____________

B) Industrial:

Customer Name	Type Equipment	# of Units	Dollar Value	Purpose (Use Codes)
______________	________________	_____	$______	____________

C) Commercial (Consumer Electronics):

Customer Name	Type Equipment	# of Units	Dollar Value	Purpose (Use Codes)
______________	________________	_____	$______	____________

D) Space Applications:

Customer Name	Type Equipment	# of Units	Dollar Value	Purpose (Use Codes)
______________	________________	_____	$______	____________

APPLICATIONS AND MARKETS (continued)

2. MARKETS: Please characterize your total 1989 sales (in $000s) of semiconductor wafer processing equipment by the following end markets, and the percent of foreign origin equipment and parts (on a value basis) contained in your sales to each market segment.

Market	Total Sales	Foreign Content (percent equipment and parts of foreign origin)
Military	$________	______ %
Industrial	$________	______ %
Commercial	$________	______ %
Space	$________	______ %

3. LOST SALES: For semiconductor wafer processing equipment, please list the top five contracts that you bid-on, but lost to foreign competitors during 1985-1989. Identify the type equipment (use letter codes on page 2 of the questionnaire), the customer, the end market, the value of your bid and the estimated value of the winning bid.

Type Equipment	Customer	Market	Your Bid	Winning Bid
a. ________	________	______	$______	$______
b. ________	________	______	$______	$______
c. ________	________	______	$______	$______
d. ________	________	______	$______	$______
e. ________	________	______	$______	$______

4. REASON SALES LOST: Please provide the reason(s) you lost the above sales. Lost sales could be related to price, delivery, technology, reliability, performance, customer loyalty, etc.

a. ________________________________

b. ________________________________

c. ________________________________

d. ________________________________

e. ________________________________

PART VI. FINANCIAL INFORMATION

1. PROFITABILITY: For wafer processing equipment and parts only, please enter the financial information (in $000s) as specified below for the years 1985-1989. Include only dollar amounts that apply to your semiconductor machinery manufacturing operations.

	(in thousands of dollars)				
	1985	1986	1987	1988	1989
Net Sales (1)	______	______	______	______	______
Cost of Goods Sold(2)	______	______	______	______	______
Operating Income (3)	______	______	______	______	______
Net Income before taxes (4)	______	______	______	______	______
Aftermarket Revenues (5)	______	______	______	______	______

(1) Trade (this should equal shipment totals from Part III of questionnaire), but excluding aftermarket revenues
(2) Includes materials and component purchases, direct labor, and other factory costs such as depreciation and inventory carrying costs.
(3) Difference between Net Sales and Cost of Goods Sold
(4) Operating income less general, selling and administrative expenses, interest expenses and other expenses (including uncapitalized R&D expenses), plus other income
(5) Service and repair work related to wafer processing equipment

2. INVESTMENT: Enter expenditures for plant, new machinery and equipment (in $000s) from 1985-1989 as requested below.

	(in thousands of dollars)				
	1985	1986	1987	1988	1989
Plant	______	______	______	______	______
New Machinery/Eqmt.	______	______	______	______	______
Totals	______	______	______	______	______

FINANCIAL INFORMATION (continued)

3. BALANCE SHEET: Please provide the balance sheet information (in $000s) as specified below for your latest accounting period. Include only dollar amounts that apply to your semiconductor wafer processing equipment operations.

(in thousands of dollars)

	Assets		Liabilities
Current Assets		Current Liabilities	
Cash and Equivalents	______	Accounts Payable	______
Accounts Receivable	______	Short Term Debt	______
Inventories	______	Current Portion of Long Term Debt	______
Other	______	Other	______
Property, Plant and Equipment (book value)		Non-Current Liabilities	
Land and Buildings	______	Long Term Debt	______
Machinery and Equipment	______	Other	______
Allowances for Depreciation	______		
Other Assets	______	Equity	______

PART VII. COMPETITIVENESS

1. COMPETITOR FIRMS: Please identify your two major domestic and foreign competitors.

	Domestic Competitors	Foreign Competitors	Country
a)	____________	____________	________
b)	____________	____________	________

2. COMPETITIVE RANKING: With regard to your major foreign competitors, please comment on your competitive advantages and disadvantages as requested below.

Competitive Area	My Firm's Advantage yes/no	Comments
Overall Technology	______	____________________
Design Capability	______	____________________
Engineering Capability	______	____________________
R & D Capability	______	____________________
Innovation	______	____________________
Price	______	____________________
Equipment Quality	______	____________________
Delivery	______	____________________
Customer Satisfaction	______	____________________
Capital Costs	______	____________________
Labor Attitudes & Availability	______	____________________
Business Environment	______	____________________
Government Assistance	______	____________________

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COMPETITIVENESS (continued)

3. PLANT SIZE/CAPACITY AND COMPETITIVENESS: Please discuss how your foreign competitor's plant size/capacity influences their competitiveness in relation to you. Consider such influences as economies of scale and production volumes, overhead costs and other costs, delivery, quality, global prospective, aftermarket service, organization, etc.

____

4. UNFAIR TRADE PRACTICES: Please comment on any unfair trade practices (e.g., tariffs or other trade barriers, market access, foreign government subsidies or incentives, dumping, etc.) that provide your foreign competitors an artificial advantage.

____

4. COMPETITIVE PROSPECTS: How do you view the competitive prospects for your firm's U.S. semiconductor wafer processing equipment operations over the next five years?

They should:
- improve greatly _____
- improve somewhat _____
- stay the same _____
- decline somewhat _____
- decline greatly _____

Please discuss the basis for you answer: ____________________

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CERTIFICATION

The undersigned certifies that the information herein supplied in response to this questionnaire is complete and correct. The U.S. Code, Title 18 (Crimes and Criminal Procedure), Section 1001, makes it a criminal offense to willfully make a false statement or representation to any department or agency of the United States as to any matter within its jurisdiction.

________________ ____

(Date) (Signature of Authorized Official)

________________________________ ____

(Area Code/Telephone Number) (Type or Print Name and Title of Authorized Official)

________________________________ ____

(Area Code/Telephone Number) (Type or Print Name and Title of Person to Contact re this Report)

COMMENTS: Please use the space below to provide any additional comments or information you may wish regarding your operations, or other related issues that impact your firm.

DEPARTMENT OF COMMERCE * UNITED STATES OF AMERICA *